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THE FIRST HUNDRED YEARS OF RESEARCH AT THE FRANKLIN INSTITUTE

BY

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Knowledge gained from experience is probably the most trustworthy. This reflection, and no capricious decision, caused Federal authorities to turn to The Franklin Institute in 1942 when it became apparent that the normal processes of research were inadequate to meet the national needs for conducting a modern war against a bold and unscrupulous aggressor. It was natural to turn to the Institute at a time of crisis for, more than a century earlier, the resources of its members had been enlisted to conduct the first technical research for which Federal funds had been appropriated. For more than a century after the initial step had been taken the members of the Institute continued their work in the interests of public welfare, with no other recompense than the reward which comes from the accomplishment of a necessary task satisfactorily concluded. The record of achievement is a memorable one and has the merit of deserving a much wider recognition than it has achieved.

Today, when men may look confidently to the magnificent laboratories of the government departments, of educational institutions, and of industry for the discoveries which, through their applications, will enrich our lives, it is no easy matter to picture that stage of civilization when the most important discoveries issued from humble attics, cellars, and barns, where individuals devoted their lives in isolation to the accomplishment of self-allotted tasks

The research methods adopted by the members of the Institute changed the picture by establishing the tradition of co-operative research, or research by a team of workers who provided a variety of skills developed in more than one field.

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

The nation had not completed fifty years of independent existence when the Institute was founded. The experiment with freedom from external control and the inter-relationship of men within the nation had absorbed so much energy that the few students of science were compelled to follow the leadership of Europeans. The value of science to the manufacturer for the production of new industries and the improvement of the processes in established industry is a familiar theme today, but we must make a mental effort to visualize a social condition in which the idea was a complete novelty existing in the minds of a few enlightened men. Only an elementary effort had been made to emancipate Education from mediaeval conditions. Scientists were still known as philosophers and were rarely to be found outside their laboratories. This remoteness from practical affairs had caused science to fall far behind invention, which had fallen into the hands of empiricists who had no aptitude for the mathematical formulas that are conventional in our day.

The time of the Institute's foundation was witnessing a change in this order. A series of inventions (notably that of the steam engine) was bringing about the Industrial Revolution that was to change the entire social context. Industry was feeling its birth pangs. In America it could not be detected by any prophetic thunderous roll of approach, not even by a distant rumble. Only by listening intently could an eager ear detect an occasional chirrup of hope, and the vision of aggregation and integration was as audacious as trying to make a suit of clothes from nothing but buttons and button-holes.

These factors must be realized before anyone can understand the significance of the Institute's role in research. The word "research" was hardly in the vocabulary of the American, when the members of the Institute undertook their bold experiments. The Republic was in its infancy. Its people abhorred pageantry and hugged to its collective breast a narrow dull level of life. It was busy, frantically busy with ax, saw and hammer; so fully occupied with its physical problems as to have little leisure for imagination. The mental atmosphere was unfavorable to major changes. "Everything may be made better" may have become an American assumption after years of experience in improving things, but no such attitude of mind prevailed in the first quarter of the nineteenth century. Fluid capital was scarce and what there was of it was invested in land, so that a manufacturer who contemplated introducing an innovation had to proceed cautiously. The normal practice was to set up a workshop and see if the idea worked. If it did, the manufacturer had to face the discouragingly slow process of selling and distributing in a country which had few good roads and newspapers to aid him in reaching consumers.

When The Franklin Institute was founded, its members did not contemplate the establishment of a research laboratory in the modern

conception of the term, they were content with the more modest hope of developing an "experimental workshop," with the intention of assisting national manufacturers and of encouraging them to make the nation independent of the products of British factories. The Committee on Inventions (the name was changed to the Committee on Science and the Arts, which it still bears) was active in assisting the individual inventor, but the need was recognized for a broader framework which would embrace fundamentals of more general aspects. The idea took root almost through accident.

DRY DOCKS

A design for a dry dock had been submitted for the Institute's approval when it occurred to some members that the whole subject was so little known in this country that it should be considered in its broadest aspects. "The large ships of war of the nation are at present suffered to decay when serious repairs are requisite, which might easily be performed if dry docks were in existence in the Union. The danger and expense from this neglect require immediate attention, and the national welfare demands the establishment of docks without further delay." The common practice of "heaving down" a ship in need of repairs to the hull was condemned as dangerous, expensive, and incomplete. American shipowners who found their larger vessels in need of such repairs were in the habit of seeking a charter for a voyage to Europe where the vessel could be dry docked. The case as submitted to the Institute justified a thorough investigation by a group of experienced naval constructors so that the report they presented might serve as a foundation upon which either public or private enterprise could build.

A special committee was accordingly appointed to undertake this work in 1826. Their illustrated report, published in the following year,[2] reveals with what enthusiasm the members performed their task. They described the methods adopted in Europe for the construction and operation of dry docks, capital and maintenance costs, and generally described the means by which the shipbuilding industry might provide a remedy for a major deficiency in its facilities. A special feature of this report which shows the progressive spirit animating the Institute members is contained in a paragraph in which the employment of a steam-operated pump was considered. This, it should be observed, was at a time when there were a bare score of steam engines operating in the country.

Nothing of a similar nature had been attempted in this country. The pioneer effort at applying team-work to the investigation of industrial problems was an accomplishment which reflects the highest credit upon the public spirit displayed by the original members, who thereby set an example which was to be followed in later generations.

[2] JOUR. FRANKLIN INSTITUTE, Vol. 3, p. 3 (1827).

WATER WHEELS

It was the era of water power as a prime mover for factory operation. Moreover, it was the time when metal was replacing wood and machinery was rapidly being introduced. Rotary motion had been applied to the steam engine but, while steam was becoming widely adapted to both land and water transportation, it did not appear to offer any serious challenge to water power, which was so freely abundant that almost every village had its mill. Yet, in spite of its antiquity and its widespread adoption, the water wheel had been sadly neglected by the men who built and operated it. The theories, such as they were, upon its power were frequently contradictory. A few experiments had been made by Bossut in France[3] and more extensive investigations by Smeaton in England[4] but these studies were ripe for revision with sixty years' experience to draw upon. The work of individuals was to be supplemented by the combined labors of a group of men with broad qualifications. A special committee was appointed to "make experiments of sufficient magnitude to fix the data from which calculations could be made with accuracy" upon wheels of various types. The committee organized its operations to make the most comprehensive study the available funds would permit.

The question of funds enables us to introduce the comment that the members of all the Institute's special investigation committees accepted their tasks without any recompense or reward. The Institute rarely had the money or the materials necessary. Where the committee members or the Institute could not pay the expenses, it was necessary to raise funds among the members at large or from favorably disposed outsiders. In this case of the water-wheel study an appeal for funds resulted in the collection of $2000 and permission from the city to use the water works and dams for experiments. At a later date permission was granted to use one of the city water mains. A plot of ground at Vine and Ninth Streets was offered by Messrs. Rush and Muhlenberg[5] on which a temporary building was erected in which experiments could be made, and four experienced millwrights were engaged to construct models. It is worth recording that these voluntary workers took their responsibilities so seriously that they introduced a fine of 12½ cents to be inflicted upon those of their number who arrived late at meetings and one of 25 cents for failure to attend.

The millwrights constructed a water wheel with a diameter of 20 feet at a cost of $1300. No sooner had the wheel been completed than

[3] Charles Bossut, "Determination generale de l'effet des roues mues par le choc de l'eau,' *Histoire de l'Academie Royale des Sciences*, 1769, p. 477.

[4] J. Smeaton, "An experimental Enquiry concerning the natural Powers of Water and Wind to turn mills and other Machines, depending on a circular Motion," *Royal Society Philosophical Transactions*, Vol. LI, Part I, 1759, p. 100.

[5] These were the successors of Oliver Evans who had done so much to develop the steam engine.

it demonstrated the capricious nature of this form of power. Winter set in, and the frosts caused a postponement of the investigations until the spring of 1830.

When work was resumed it proceeded at a rapid pace. Over 700 experiments were conducted with breast, overshot, and undershot wheels. Special devices were contrived for measuring the amount of friction on the shaft under different loads and the amount of power furnished by wheels of various diameters. Different types of buckets were tried under varying heads of water. It was intended that nothing should be left to chance in determining the best construction of a wheel in relation to the available flow of water. The information provided on the overshot and undershot types was of special value, since most of those adopted in this country were of the breast type.

The results of the experiments were ably digested and published over a period of years in the JOURNAL, with many tables giving details of the intensive tests.

STEAM BOILERS

While the work of this committee was proceeding, attention was drawn to a phase of power which was to supplant water. Professor W. N. Keating, one of the founders of the Institute, mentioned that "Numerous accidents had occurred on steam boats, the effect of which is to impair the confidence of the public in the merit of an invention which has shed vast honor upon the American name and which has essentially contributed to the prosperity of the country." He proposed setting up another special committee to investigate the causes of these disasters and to make recommendations to reduce the frequency of their recurrence. It was most appropriate that such work should be undertaken in the city which had been the site of the first successful steamboat trials and the original application of high pressure steam in boilers. A special committee was promptly appointed.

This committee was fortunate in securing as its chairman the energetic Alexander Dallas Bache, who was at the time Professor of Natural Philosophy and Chemistry at the University of Pennsylvania. Largely through his guidance the committee adopted a scientific method for their investigation. The first step was to issue a circular letter inviting correspondence from all those who had had any experience of a boiler explosion and had collected evidence upon its apparent cause. The replies were published in the JOURNAL and later republished in pamphlet form.[6] The number of responses to the letter was disappointing and the opinions expressed in the replies were inconclusive, but the distribution of the pamphlet provoked a flood of replies of much higher value. With the testimony these provided, the members of the committee set about correlating the evidence. At once it became evident that the

[6] "Communications received by the Committee of The Franklin Institute on the explosion of steam boilers," Philadelphia, The Franklin Institute, 1832, 32 pp.

absence of any reliable criteria led to a wide conflict of opinion upon the strength of the materials employed in boiler construction and the methods of joining the plates.

The cylindrical iron boiler was in general use, having replaced the old oak-timbered boiler with its metal braces. But the greatest confusion reigned upon the properties of the metal employed. There was a lack of knowledge that imprisoned steam possesses some of the qualities of a high explosive, and the prevailing ignorance permitted the employment of inexperienced men to operate the boilers. Investigation had revealed that boilermakers had no accepted standards; safety factors were either unknown or not observed.

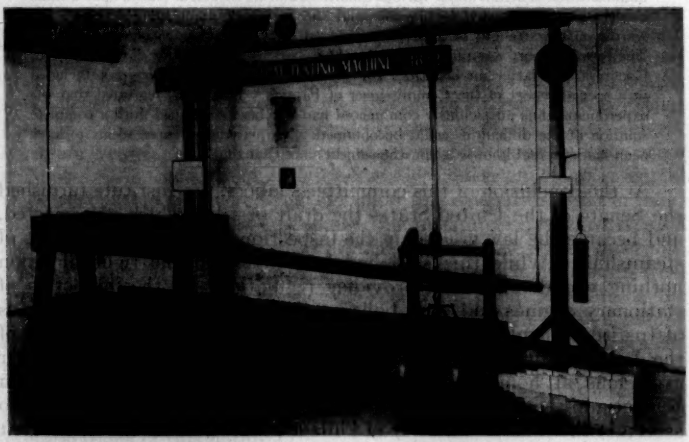
Since no one had clear views upon the pressures which were required nor which could be held in restraint by the materials of construction, the committee determined to arrive at some criteria which would be of service for the future. The members divided into two groups, one of which was to concentrate upon investigating the properties of steam with special apparatus designed for the purpose, the other was to wrestle with the problem of the strength of the metals (iron and copper) used for boiler construction. The members of the Institute were asked to cooperate in the raising of funds to defray the cost of building the necessary apparatus and conducting the experiments. Meanwhile, government authorities had become gravely concerned over the increasing loss of life and damage to property through explosions and had drawn attention of Congress to the dangerous situation which was retarding the more general adoption of steam power while European countries were freely adopting it. Congress voted a sum of money which was to be applied to gathering information.

When news of The Franklin Institute committee's work reached him, the Secretary of the Treasury (S. D. Ingham) wrote to inquire about the nature and scope of the research they were proposing to undertake, and when he had been informed he notified the Institute that he would contribute $1500 of the appropriation toward the expenses which would be incurred. This is noteworthy as being the Federal Government's first grant—so far as we have been able to ascertain—in aid of scientific research for industrial purposes. Money had been appropriated to promote surveys and expeditions for the purpose of discovering the national resources, but this was the first occasion on which funds were set aside for the conduct of experiments, the results of which were problematical and might be intangible. Parenthetically, it might be stated that the outcome proved of such high value that one cannot refrain from expressing astonishment that the government remained so indifferent to scientific research until the crisis created by the Civil War forced the President to create the National Academy of Science, the members of which were to serve as scientific advisers to the government departments.

Rapid progress was made with the work. D. H. Mason was ap-

pointed supervisor of the experiments and "an experiment house" was occupied on the northeast corner of Vine and Twelfth Streets. The experiments were conducted with no little danger to those engaged, for boilers were repeatedly taxed beyond the critical point. What the nearby residents thought about the proceedings is not a matter of conjecture. They protested energetically when the social amenities of the neighborhood were shattered by an unusually violent explosion.

A feature of this research of more than passing interest was the design and construction of apparatus for testing the strength of iron and copper. No such machine was known at the time in this country, so that it ranks as the first of its kind. The apparatus was held in such



high esteem that, after it had served the purpose of the committee it was made accessible to anyone who cared to bring the material for test to the Institute. The apparatus is still preserved in the Institute's Museum, an interesting relic of American ingenuity as displayed more than a century ago and a lasting tribute to the zeal of those early members who created the research traditions still animating the laboratory research staff.

Some of those men who had examined the remnants of exploded boilers violently denounced the practice of rivetting on boiler heads, a practice they contended weakened the metal. The investigating committee learned by experiment that rivetted joints were actually stronger than the sum of the shear strengths of the rivets. They ascribed this to friction between the rivetted plates, thus correcting a popular misconception.

This committee on boiler explosions devoted four years to its re-

searches, and its reports are to be found in the JOURNAL up to the year 1836. A summary report in pamphlet form was issued.[7] The fundamental nature of the investigation and the high value of the conclusions reached are best summarized in the Report of the Secretary of War for 1872. Writing upon the subject of experiments made at Sandy Hook in the presence of army observers, the Secretary wrote:

> It is gratifying to know that the experiments which have led to the most reliable information hitherto possessed by the scientific world on this difficult subject were instituted and conducted by an American institution (The Franklin Institute of Pennsylvania), under the patronage of our government, over thirty years ago. Those experiments were detailed in two able reports; one made in January 1836, on the manifestation of steam under various conditions and its effects, as steam, upon a small model boiler constructed for the purpose; and the other, made some months afterwards, on the strength of materials employed in the construction of steam boilers. The former report was published in Ex. Doc. No. 162, first session, Twenty-Fourth Congress; the latter, in Ex. Doc. 18, second session, Thirtieth Congress, included in a special report of the Commissioner of Patents. It is to be regretted that the experiments thus auspiciously commenced had not been continued until a complete solution of the difficulties could be obtained. No material advance seems to have been made in real knowledge on the subject since that time.

At the conclusion of this committee's labors, the Institute furnished the Senate of the United States the draft of a bill which was enacted, and became the law governing the inspection of boilers and engines of steamships. While this step had been taken in the right direction nothing was done toward providing regulations for the inspection of stationary engines and their boilers. This matter occupied the minds of Institute members for the next thirty years. Almost every issue of the JOURNAL during that time contains one or more reports of boiler explosions at home or abroad, and members of the Committee on Science and the Arts visited the scene of all local occurrences in order to ascertain the cause. The city of Philadelphia was then in the forefront of industry and, in consequence, appeared to have a disproportionate number of boiler explosions. Many of these could have been prevented had there been any intelligent regulation and enforcement of inspection. Eventually, with the continuation of preventable accidents and under pressure from the Institute, the city council was compelled to take action. The Law Committee requested the Institute to draft an ordinance which, when enacted, would ensure adequate technical provisions for observance.

A special committee was appointed in 1867 to study several drafts which had been submitted and work was proceeding in this when a terrific explosion in a local woodworking plant, in which 25 men were killed, demonstrated the criminality of any further delay in the passage of protective regulations. This last tragedy was one that could easily

[7] Franklin Institute Committee, "Report on the explosions of steam boilers," Philadelphia Sherman & Co., 1836, 48 pp.

have been avoided since it was caused by the common practice of having one safety valve on two connected boilers. The draft ordinance which the Institute provided was quickly adopted and inspectors were appointed to see that its provisions were enforced.

During the Civil War, the President and the service departments were inundated with ideas advanced by patriotic citizens to improve the armament, ships, and navigational methods then prevailing. In order that competent minds should be employed to sift the grain from the chaff, the President created the National Academy of Sciences, to whose members all technical problems relating to the government departments might be referred for investigation and advice. A joint commission composed of representatives of the Academy, the Navy department, and The Franklin Institute was appointed in 1864 to investigate and compare "the results practically to be obtained by different measures of expansion of steam." This commission had its origin in the belief held by B. F. Isherwood, Chief Engineer of the U. S. Navy, that there was no advantage to be gained "in the use of steam expansively in steam vessels," an opinion that was vigorously opposed by other engineers. As was so frequently the case in pioneer efforts at research, the investigators discovered that no apparatus existed to assist in making experiments. As was customary the Institute representatives on the commission reported progress in their labors at the stated meetings. On the presentation of their second report, in which no results were announced because the reporter was restricted to an account of the apparatus devised for the experiments, a lively debate ensued among the members. Opposition centered upon the employment of a special dynamometer and not to the causes indicated.

The nature of this discussion is indicative of the keen interest displayed by Institute members and of their qualifications to undertake investigations of this nature.

In those early days of steam engineering, builders were accustomed to specify in the contract of sale, that their engines and boilers were of certain size and horsepower. That the engine came up to contract in the specified size could easily be determined with a foot-rule, but the horsepower delivered by the boiler furnished the basis for a very considerable divergence of opinion between buyers and sellers. In 1871 an appeal was addressed to the Institute inviting the members to establish a standard acceptable to buyers and sellers. As this was a vexing question it was decided to conduct experiments to ascertain how the horsepower should be determined.

Tests were made with two boilers known as double tank, with separate furnaces, each boiler having 500 sq. ft. of heating surface and 16 sq. ft. of grate surface. These boilers had been purchased by a local firm whose representatives had demanded a test by indicator, to which the

seller demurred. As an incidental outcome of the Institute tests, the seller had to provide an additional boiler before the specified 100 horsepower was delivered. From this one may judge the extent of the divergence of opinions and the necessity of a standard which the Institute now proposed to establish.

In an interim report, the special committee reviewed the origin of the term "horsepower" and the methods of measuring nominal, indicated, and actual power. They expressed a belief that uncertainty would be removed if the horsepower were to be specified in terms of the weight of fuel to be used per horsepower developed (that is, per cubic foot of water evaporated per hour). They also recommended that the term horsepower applied to a boiler should invariably be qualified as nominal, indicated, or actual in all ratings, and deprecated the practice then in use of rating a boiler's horsepower from the amount of work performed by the engine it operated.

The committee, meanwhile, pursued its research for the purpose of establishing a reliable method for calculating the heating surface required to evaporate a cubic foot of water in different types of boilers. Having collected information from numerous sources they were able to present a convincing comparison of the performance of the various types of boilers in use.

WEIGHTS AND MEASURES

However, steam boilers and steam engines did not exhaust the research activity of the members. When the Commonwealth of Pennsylvania was confronted in 1834 with the need for enacting a statute authorizing the provision of "metallic standards" to facilitate the inspection and regulation of the weights and measures in use, a copy of the proposed bill was submitted to the Institute with the request that its members make an investigation into the whole subject and to submit such amendments as they thought necessary to make the Bill effective. After a close examination of the systems adopted in the United States, Great Britain, and France, the committee which had been appointed raised objections to the projected legislation and, as an alternative, offered a Bill containing provisions for a system of weights and measures, and a supplementary Bill establishing the legal denominations which more closely conformed to other standards adopted in the country. The suggested Bills were adopted, and the legislature invited the Institute to supervise the construction of the standard units.

It is noteworthy that the manner of approaching this problem was adopted thirty years later when a committee of the National Academy of Sciences was requested by Federal authorities to inquire into the wisdom of adopting the metric system of weights and measures. The two methods of investigation were identical.

GAS LIGHTING AND HIGHWAYS

The prophets were not without honor in their own city. Many of the citizens had raised a violent protest against the proposal to introduce gas lighting. It was condemned on the wildest assumptions to be a menace to public health. The city councils adopted a more enlightened view but with a lack of empirical knowledge could only meet assumption with counter-assumption. Finally, it was decided to dispatch Samuel Vaughan Merrick, moving spirit in the founding of the Institute, and a member of its Board of Managers for 22 years, on a tour of inspection of those European cities which had adopted gas lighting. It was upon Merrick's recommendations that the city gas works were built and the system of street lighting was designed.

In the year 1843 the Select and Common Councils of the city presented a joint resolution to the effect that "The Franklin Institute be requested to communicate to the Councils any information they may think proper, in relation to the best modes of paving highways." With a diligence equalling that of all the other special committees, that which was set up to deal with this problem plunged into its work, interviewing experienced men, writing to various other cities with heavy traffic, and generally assembling all available knowledge on asphalt (just introduced in Paris), wood, and stone-block paving. While this material was being gathered and correlated, members of the committee made a survey of the soil and drainage of the streets. The report presented to the Councils made recommendations for the suitable paving of first and second class highways, drew up the necessary plans and specifications, offered suggestions for the superintendence and the manner of executing the work, and tendered an estimate of the costs.

STRENGTH OF MATERIALS

The Committee on Science and the Arts was still actively engaged upon the investigation of individual problems submitted to them. They rarely departed from the practice of examining new inventions or processes. This work did not involve the conduct of original experimentation, but, in 1844, this committee was asked to conduct an impartial investigation into the causes of an explosion of a gun on the frigate *Princeton*. This vessel was the object of unusual interest at the time she was launched since she was the first ship of war to be fitted with a screw propeller and carried two 12-inch guns, the most formidable weapons that had been constructed. The trials of this unique vessel were converted into a festive occasion through the presence of the President, John Tyler, members of his cabinet and Congress, and other distinguished visitors. One of the monster guns exploded, killing the Secretaries of War and the Navy, several other guests, and the men of the gun crew.

It is uncertain how this investigation came to be referred to this standing Committee but, judging from the facilities provided for the

members, there is little reason to doubt that the terms of reference issued from official sources. Inquiries into the strength of wrought iron guns had been conducted previously by officers of the armed forces, but the investigating officers had restricted their reports to evidence obtained in firing tests. It seems clear that there were no data existing to enable them to form any conclusion upon the qualities of wrought iron other than what they could extract from the visual examination of the fractured parts when a gun had the misfortune to burst. The passages quoted to support the conclusions were, for the most part, taken from a French treatise on artillery which appeared to be the standard work of reference for the Bureau of Ordnance.

As the Institute had accumulated a large volume of knowledge on the strength of materials, due to its possession of the famous apparatus designed for this work, it seemed logical for the Federal Committee on Naval Affairs to turn to it for information on the strength of wrought iron and for an opinion upon the suitability of the material employed in the construction of the 12-inch guns, the explosion of which had very nearly robbed the country of its principal leaders. Without some overall official sanction it is improbable that the Committee would have been granted the privileges it enjoyed.

The members of the Committee visited the *Princeton* to examine the exploded gun. At their request they were furnished with a portion of the original metal from which the gun was made and they were given detailed information on the methods and processes employed in its construction. The members were of the opinion that errors had been made in the choice of metal, in its working, and in its welding. They declared that wrought iron should not be used in the construction of guns of large caliber until knowledge of its treatment had expanded. As was customary in established practice the Committee's conclusions were reinforced by an impressive array of results obtained in practical tests and in comparisons between the gun-metal and other specimens of wrought iron. The apparatus designed for testing the strength of boiler plate was used freely to test the resistance of the gun-metal in its bar form at different stages of its fabrication, and of sections cut from various lengths of the exploded barrel. The Committee disclosed that they had made a group of tests by which their knowledge of heat treating had been expanded, but the results were omitted from their report as the matter lay outside the terms of reference.

Professor Joseph Henry of Princeton University was a member of this committee. From observations made upon the nature of the fractured metal he resolved upon conducting a series of experiments which ultimately led him to form a theory upon the conservation of energy which, had he been able to overcome an innate dislike to publishing the accounts of his researches, would have established his reputation as a pioneer in this field.

SHIP PROPULSION

During "the roaring Forties" the whole country was humming with the sound of whirring wheels as machine-made goods began to replace the products of handcraft. New inventions were urged upon the buying public supported by most extravagant claims. Some spirited discussions were opened when two types of product entered into open competition. One of these discussions centered upon the relative merits of propellers and paddle-wheels for steamship propulsion. This question began to assume an additional importance when the public mind became agitated over the inauguration of mail steam services in Britain and the proposals for an increased steam navy at home. Government bureaus were still without research departments and since the Institute had established a reputation for competent researches and impartial judgment, the Secretary of the Treasury, Robert J. Walker, appealed to the members for an unprejudiced opinion upon the subject which had sharply divided maritime circles. Specifically, they were to supervise tests made with Hunter's submerged paddle-wheels and Loper's propellers.

They were presented with a report of trial-runs made by the *Spencer* in New York Bay in 1844, in which both types of propulsion had been tested. This report was carefully analyzed and some theoretic conclusions deduced. The members of the committee then accompanied the vessel and the *Water Witch* on some additional trials of a more exhaustive nature between Newcastle and the Delaware Breakwater, in which the paddle-wheel and the propeller were interchanged. The results showed that with the same power Loper's propeller was 4.6 times as efficient as the submerged paddle-wheel, an empirical result that agreed with theoretical anticipations.

LIGHTHOUSES

Shortly after his installation as the Secretary of the Smithsonian Institution, Professor Joseph Henry was appointed to the Lighthouse Board. It was a lamentable fact that coast-wise lights had fallen far behind those of Europe, so that an experienced physicist had little difficulty in finding opportunities for improvement. One of his first recommendations was that Fresnel lenses be installed in all the lighthouses to secure improved illumination. Four models of the proposed installations were exhibited at a stated meeting of the Institute, April 19, 1849. These attracted so much attention that a committee was appointed to investigate their properties and to compare them with the lights in general use. The report lacked nothing of forthrightness in condemnation of the lights in use which, it was declared, were so inferior to those introduced into European lighthouses, as to be unworthy of comparison. The committee members expressed themselves strongly in favor of the Fresnel refracting lenses, ruefully recording that only one light of this kind had been installed in this country while the

coasts of Europe were lighted by 300. After collecting and analyzing a considerable amount of technical information upon different types of lenses, the members expressed the pious hope "that our whole coast, on both oceans, and on the lakes, may speedily be provided with this brilliant, economical and admirably devised gift of the science and art of the Nineteenth Century."

This report must have enheartened Professor Henry, who was under strong pressure from members of Congress urging the claims of their supporters to have their products purchased out of public funds. The approval of a highly respected technical body furnished him with strong moral support in his efforts to secure a greater degree of safety for mariners.

FIRES IN THEATERS

The years 1850–1852 were marked by an increase in the numbers of fires, which had caused the destruction of much property and loss of life. When the attention of Institute members was drawn to this situation by one of their number a committee was appointed to prepare a memorial to be submitted to the Common Council of Philadelphia in the name of the Institute recommending the passage of an ordinance which would not only prohibit the erection of wooden buildings, but would determine the height, thickness, and materials for the walls in order to reduce the ravages of fire.

This was the introduction of a subject which, like that of steam boilers, was to receive attention intermittently for thirty years and was to end by an investigation which was to have far-reaching effect.

In 1853 the firm of Jos. S. Elkinton and Sons had a factory destroyed by fire. Three years later the firm had another fire, caused apparently by spontaneous combustion of sawdust. The firm appealed to the Institute for an opinion upon the question: Would sawdust situated forty feet from any flame ignite spontaneously? Investigation revealed that the sawdust was packed around a tank for rendering grease. The sawdust had been in use for about nine months and the tank was heated by steam at about 50 lbs. pressure to the square inch, equivalent to a temperature approaching 301° F. The members of the Committee found a report of a fire in London where the conditions had been almost identical, and this led them to conclude that the sawdust, charred by the distillation of moisture and volatile matters in the wood, at low temperature was more highly inflammable than normal sawdust at a higher temperature. The Committee recommended that builders be cautioned against allowing joists to run near flues, through hot air chambers, or near boilers and steam drums.

The nation continued to be shocked by conflagrations involving a heavy loss of life. The number of fires in theaters and public halls in the United States was out of all proportion to those experienced in other countries. A member, C. John Hexamer, presented a paper before the

Institute on the subject and the members present were so impressed by his material and, realizing the inadequacy of the protective measures he advocated, decided the subject was of sufficient importance to be worthy of more comprehensive investigation. They appointed the usual committee to undertake the necessary research and to submit a report that would contain recommendations for preventive measures which would insure a higher degree of safety for audiences and property.

The special Committee pursued their investigations over the period of a year, but their time was well spent, as is apparent from their report,[8] which is a model of its kind. It should be remembered that the members of the Committee were confronted with conditions which differed materially from those prevailing today, but many of the recommendations contained in their report as obligatory were so fundamental that they are universally applied today as essentials to public safety and the preservation of property. The greatest number of fires in theaters originated in the lighting apparatus, which was either coal gas or, in the United States, coal oil. The Committee was emphatic in endorsing the new incandescent electric light, the installation of which was regarded as the most necessary reform in theater construction. The members condemned the use of coal and wood stoves for heating the buildings. After six months of experimenting to discover a suitable process they recommended the impregnation of the scenery materials to render them fireproof. As proof of the exhaustive nature of their work, they mentioned that they had tested all the types of fireproof paint on the market before approving the method recommended.

All the workshops and paint lofts were to be banished from the theater proper and iron doors were to be provided to add to the physical separation. Then follows the recommendation for the universal adoption of the fireproof asbestos curtain. This adjunct to safety had not been tried in this country but the Committee initiated their own experiments with woven asbestos and made a final large scale test at the Brooklyn Navy Yard which convinced them that the asbestos curtain was an essential in all theaters. As a precaution for isolating the fire, should there be an outbreak while the theater was unattended or when opening for a performance, it was recommended that the curtain remain lowered until within fifteen minutes of the performance beginning.

Altogether, thirty-eight precautionary measures were recommended. Many of these did not deal with new materials which had become available but were the application of common sense principles to the provision of greater safety. The marking of all exits with illuminated signs; the opening of all doors outward on the street; the abolition of long unbroken rows of seats in favor of adequate aisle spaces; the fixing of all seats to the floor with spring attachments to throw back the seat when it was not occupied; the use of hair instead of paper wads in fire-

[8] JOUR. FRANKLIN INSTITUTE, Vol. 115, p. 430 (1883).

arms used on the stage; and the provision of an automatic sprinkler system were among the other precautions recommended to reduce the danger of an outbreak of fire and to facilitate the prompt departure of the audience should a fire break out. The public authorities were not excluded from their share of responsibilities in regard to the observation of proper precautions, since the appointment of qualified persons to see that the precautionary measures were enforced, together with a brief outline of their duties, was incorporated in the recommendations advanced in the report.

In this report we have the genesis of a safety code for the construction and equipment of theaters and public halls compiled with such foresight that the majority of its provisions have survived the passage of time.

Not all the research undertaken by the Institute was of such general significance. One diversion from the broad highway of social progress into a bypath was offered when the roof of a church on Eleventh Street above Spring Garden, Philadelphia, collapsed without warning in 1852. The minister of the church appealed to the Institute for advice, so that when reconstruction was begun any structural defect in the original might be remedied. As there was an obvious public service to be gained in an inquiry of this nature where the safety of audiences and congregations was involved, the subject was accepted for investigation. Models of the roof and two of the trusses ($\frac{1}{8}$ scale) were made, and weights were applied until signs of fracture were observed. From calculations made as a result of these experiments it was found that a roof weighing 30,000 lbs. had collapsed when the trusses were designed to support more than twice that load. Attention was then given to the timbers and an examination showed them to have imperfections in too numerous knots. Moreover, the timbers had been cut across the grain, which it was judged rendered them unsuitable for the purpose to which they had been put. It was also pointed out that the danger of a heavy snowfall had not entered into the calculation of the roof supports. It was recommended that the trusses should be designed to support not less than three times the weight of the roof.

SCREW THREADS STANDARDS

A task of much greater importance was assumed in 1864. The president of the Institute, Williams Sellers, read a paper on "A System of Screw Threads and Nuts," in which he deplored the prevailing practice of manufacturers in following their individual caprices when designing screw threads. He pleaded that some consideration might be given to the speed and ease with which an engineer could replace a defective or broken screw and nut. The speaker wasted no time upon describing the abundant variety to be found among American screws and their threads, for his hearers were fully informed upon the disadvantage of

the lack of standards which complicated their repairs. The audience responded to his plea that the Institute should take the lead in advocating a uniform system of screw threads on the lines of the British example in that field. A Committee was promptly appointed to draw up a system of standards which would meet American requirements.

As this committee's researches progressed, the members were greatly impressed by two features they had not contemplated. First, the variety of screw threads in use was so much greater than was thought that a standardized system, if adopted, would effect economies far beyond their expectation. Second, the interest displayed in their labors indicated that success with the standardization of screw threads would induce the extension of standardization to other manufactures. From this latter observation may be inferred the reason why the Institute was in the forefront of the agitation for the establishment of a national Bureau of Standards.

The committee's report was sent to the Chiefs of Ordnance of the Army and Navy, the Quartermaster General, the Chief of the Engineering Corps, the superintendents and master mechanics of railroads, and all mechanical and engineering societies with the request that they support the movement for the general adoption of the system and to require that all construction under new contracts should be carried out in accordance with the provisions of the recommended standards. The government departments promptly adopted the system. In 1872 the Master Car Builders' Association adopted it as their system of standards and so hastened the action of those railroad companies that had deferred embracing uniformity. Eventually the system met with general acceptance and what had been known as the Franklin Institute system became the United States Screw Threads Standards.

The Institute was now committed to so much research activity, either by members of the special committees appointed as occasion arose or by the Committee on Science and the Arts that the facilities afforded for the conduct of experiments were quite inadequate. In presenting the annual report for the year 1865, the President spoke proudly about the improvements which had been made. After mentioning the improvements carried out in the Lecture Hall, he commented upon the laboratories adjoining that room, which had undergone extensive repair, had been furnished with new cases for apparatus, and had been provided with both gas and water supplies. "An evaporating closet . . . to answer efficiently to the demands of modern experimentation" had also been added. One of the rooms had been converted into an efficient dark room. Ten years later, in response to the demand, a new and improved machine for testing the strength of materials was purchased. The modest hopes of the founders that the Institute should have an "experimental workshop" were being realized.

LIGHTNING PROTECTION

The Institute had acquired a merited reputation for its interest in the public welfare, and local authorities repeatedly sought its assistance when confronted with technical problems. In the year 1866 the city council asked for advice upon an adequate system of protection against lightning for the Blockley Alms-House. As most of the members were acquainted with Franklin's work upon lightning rods, no special committee was needed for this problem, which was referred for quick action to the standing Committee on Science and the Arts. The report presented by this committee is noteworthy because of the care devoted to fundamentals as well as to the specific needs, special attention being devoted to the height and number of rods so that the entire group of buildings was protected. The care taken to insure the safety of a long structure would serve as a model for a phase of lightning protection which is still neglected.

RAILROAD SIGNALS

It will be clear from what has been written that the researches promoted by the Institute were largely devoted to the regulation of dangerous practices accompanying the rough and tumble development of new industry, and to the removal of hazards which were making progress expensive in human life and property. One of the most notable expansions in the growing nation had been in the railroads, which had mushroomed and were destined to undergo a feverish promotional activity after the war between the States. Just as in our days when the individual States cling to capricious automobile regulations to the perplexity of visitors, the newly developed railroads had their own ideas upon dangers and the signals to be employed in avoiding them. This caused much confusion and a number of accidents arose from mistaken signals. Members of the Institute perceived the need for the adoption of a uniform code of signals acceptable to all railroads and, with rare foresight, declared that unless uniformity was achieved the danger of the existing variety would be increased as the railroad systems expanded, as they did with astonishing speed. Following the usual practice a special committee was appointed to draw up a code of signals which was to be presented to Congress for incorporation in a Bill establishing uniform signals on all the railroads in the country.

The manual and whistle signals between conductor and engineer were defined; the ringing of a bell when the locomotive was leaving a station was to be made obligatory; the train crew was to be responsible for placing detonators behind a stalled train; and many others of the familiar signals were included in the code. The provisions of the code were enacted into law and have existed to the present time with one exception. Green lights and flags have replaced the white which was recommended.

ASTRONOMY

The next research group was to invade entirely new scientific territory. The total eclipse of the sun which was to occur in 1869 excited a great deal of interest among the members, who petitioned the government to appropriate funds to permit its observation. The official response was inadequate. The members thereupon resolved to organize a group of volunteer observers under the direct supervision of the Resident Secretary, who was to coordinate their efforts with the national observers under the superintendent of the *Nautical Almanac*. The group, known as the Philadelphia Photographic Expedition, centered its activity on Burlington, Iowa, and equipment was collected from various sources so that three observing parties might be formed, each equipped with a 6-inch telescope and photographic apparatus. The tasks of the three groups had been well organized and the results obtained were gratifying. Satisfactory photographs were taken at various stages of the eclipse, and some excellent pictures were obtained of the corona.

In 1932 a second solar eclipse party was dispatched to Conway, New Hampshire. This party was unusually well equipped with cameras 85 and 40 feet long, motion picture cameras, coelostats, and pyrheliometric equipment. Unfortunately, the weather was not propitious for observation. Although the greatest care had been exercised in the choice of a location and the selection had been made after an intimate study of weather conditions, the site chosen chanced to be one from which only few photographs could be taken because of clouds.

PETROLEUM

After the successful drilling of the first oil well in Pennsylvania the use of petroleum spread rapidly. The refining methods were primitive and by no means as efficient as they were to become. As a natural consequence a number of oils were marketed for domestic illumination which had dangerously low flash points. The widespread and careless use of these oils by persons ignorant of the inherent dangers led to an unusual number of fires in which individuals lost their lives or were severely burned. During the year 1871 the number of out-breaks increased by 40 per cent to the general alarm of the authorities. The apprehension of unrestrained casualties attributable to this hazardous form of indoor lighting stimulated the Institute members to inquire "into the causes of conflagrations and the most efficient methods of prevention."

Investigation of the oils on the market brought to light the popularity of an oil containing appreciable proportions of benzene and naptha because the inclusion of the volatile elements caused a brighter flame than the more stable but safer oils. The state inspectors were authorized to inspect only coal oil and kerosene. Anything that was sold

under other names was free from their condemnation however hazardous it might be.

The research committee appointed to investigate the question presented two reports. One of these, signed by the Institute's secretary, Dr. William H. Wahl, reflected what was by far the most intensive study of the light petroleum oils that had been made up to that time. The hazards accompanying the indiscriminate use of these lighter oils were so clearly demonstrated that the other members of the committee recommended that the State Legislators pass laws to restrict their sale and to give powers to the inspectors to condemn any lamp fuel which did not accord to the committee's definition of a stable lamp oil. The Legislature was not slow to act upon this expert advice upon the means of curbing the increase in household disasters.

ELECTRICAL ENGINEERING

The use of electric power began to intrigue members of the Institute at an early date and in 1877 it was proposed to purchase "a Dynamo-Electric machine capable of producing not less than 1200 candles' light." Reverting to the experience of boilers where sellers and buyers were prone to have divergent views upon the power produced, the members proposed to invite makers to send in their dynamos for practical tests. The members were not going to accept any dynamos on the strength of unsubstantiated claims, but the question arose: How did one test a dynamo?

Five dynamos were submitted for the comparative test which was to be conducted by a special committee whose members promptly divided themselves into three sub-committees responsible for different phases of investigation to make photometric, electric, and dynamic measurements. Five types of dynamos were subjected to test: a large and a small Brush, a large and a small Wallace-Farmer, and a Gramme. The selection of Elihu Thomson as a member of the investigating committee caused the elimination of his own efficient dynamo from competition. After exhaustive tests it was decided to recommend the purchase of the small Brush dynamo.

That portion of the committee's report which dealt with electrical measurements was a classic of simplicity and directness. It describes in detail the procedure followed, for it must be recalled there were no meters available for measuring voltage, current, or resistance, and the investigators had to work with galvanometer and Wheatstone bridge. The methods adopted were so admired that they were generally followed until the Institute issued the report of later research. When the first International Electrical Exhibition was organized by the Institute in 1884, the members proposed to take advantage of this unique assemblage of material to establish a code for testing electric dynamos. For this occasion sub-committees were formed to conduct tests and to report

upon the efficiency and duration of electric lamps, signalling apparatus, batteries, and telegraphs in addition to the dynamo tests. The various reports were published in successive issues of the JOURNAL and later were collected for publication.

Some idea of the esteem in which the work of these committees was held may be gathered from the laudatory comment extracted from a contemporary journal.[9] "The tests of dynamo-electric machines, made in 1885, under the auspices of the Franklin Institute, are undoubtedly the most reliable and complete of all the impartial tests which have ever been made and published, and they therefore afford the practical engineer an excellent opportunity to deduce proportions, dimensions, and constants, to assist him in designing dynamos, especially as the machines which were tested are among the best that are made." The writer declared that the previous practice had been to build dynamos by guesswork and then to try them to "see what they will give," but that with the results of the Institute's research the machine could be tested in all its parts so that it can be constructed to give desired current and potential.

PAVING OF STREETS

About this time there was a revival of activity on further behalf of the local community. Recalling that the Institute had been instrumental in making a survey upon which arrangements might be made for the paving of the streets of Philadelphia, the city councils were dissatisfied with the condition into which the cobbled streets had fallen. They wished to have a thorough investigation made into the problem of the use of cobblestones.

Two expert civil engineers were named by the Institute to carry out this work and, as was to be expected, their report revealed a comprehensive study of the subject had been made. The cause for dissatisfaction with the cobbled streets apparently lay in the ineffectual method of maintenance and repair. Superior repair methods were defined. There were still many narrow streets in the city that had to bear heavy traffic (50 heavy wagons or trucks an hour constituted "heavy traffic") For these streets, the experts recommended the substitution of granite blocks for cobblestones. In spaces around public buildings, hospitals, etc., where quiet surroundings were required, the pavement should be of sheet asphalt. Macadam roads were recommended for suburban areas. In each case detailed instructions were provided for the manner in which the materials should be chosen and the roadways constructed.

WATER SUPPLY

The Select and Common Councils of the city found themselves the storm center of an agitation growing out of the inadequacy of the city

[9] Carl Hering, "Practical Deductions from The Franklin Institute Tests of Dynamos,", *The Electrician and Electrical Engineer*, November, 1886; p. 423.

water supply and the pollution of its sources. The members of the Institute had already protested about the pollution of the Schuylkill River which was the principal source of supply and at the request of the councils had made an investigation of the various pumping stations and reservoirs. The Wissahickon, Perkiomen, and the upper Delaware Rivers were explored for the purpose of extending the sources of supply. But by 1885 the industrial development of the city had made the water supply inadequate and the Mayor was authorized to address a further appeal for aid to the Institute. A commission of five members was recommended, two of whom were drawn from the membership, to conduct a thorough investigation of the entire subject of the water supply and to make recommendations which would provide for future needs. Their report contained specific recommendations for the installation of pumping machinery and subsidiary apparatus, the completion and extension of reservoirs, and the management of the stations. It is interesting to learn that the use of meters for the prevention of waste in factories and public buildings was among the improvements recommended.

SMOKE NUISANCE

A startling reminder that Philadelphia had become a prosperous manufacturing city was conveyed to the members when the Grand Jury roundly denounced the growing smoke nuisance in the city. With a sense of responsibility for the public welfare, the Institute members voluntarily took action and undertook an investigation of the situation in 1892, but their recommendations for the remedy of a growing menace to health did not animate any official interest. Five years later the situation had grown so much worse that the need for immediate action could no longer be ignored. The Board of Health addressed a request to the Institute for cooperation with a view to taking action which would achieve abatement of the smoke nuisance created by the increased use of bituminous coal in industrial plants. Among the recommendations made were those for a campaign to educate firemen and engineers in the proper use of their furnaces and to extend the use of anthracite.

LOCOMOTIVES

The reputation of the Institute's research committees for exhaustive and impartial treatment of controversial subjects gained for one of them the position more or less, of arbiters in a contentious railroad problem. This was a joint committee of the Institute and the American Railway Master Mechanics Association created to "investigate the hammer-blow, or magnitude and variation of pressure, of locomotive driving wheels, on the rails of a railway." The members of the Association were familiar with the diversity of opinion amongst leading engineers, many of whom contended there was no wave force, or so-called hammer-blow, from the imperfect balancing of the driving wheels. It is not improbable

that these members were among the principal disputants, with the Institute members in the role of umpires.

The committee arrived at the conclusion that engines considered most perfectly balanced by counter-weights in the crank wheel did create a great disturbance in a vertical direction, causing a wave force that might be compared to a hammer-blow, that had a destructive effect upon rails and bridges dependent upon the weight and velocity of the moving parts. Having arrived at this conclusion, the members of the committee found themselves unable to measure the force of this hammer-blow, but they recommended strongly that steps should be taken to measure it and, in the absence of any appropriate apparatus, they designed a dynamometer which was believed competent for the purpose. As this would cost $6000 to build, it was suggested that the railroad companies, who would be the beneficiaries of the knowledge to be derived from it, might undertake to bear the expense. The suggestion was not followed but the problem of the hammer-blow increased so rapidly in significance that the railroads were compelled to seek a solution, which they did in their individual ways.

COMMITTEE ON SCIENCE AND THE ARTS

Allusion having been made to the Committee on Science and the Arts, it becomes necessary to say something more of its purpose and to indicate the wide nature of the research it had undertaken. From the time of its inception, this standing committee had accepted for study any scientific idea or invention submitted to it. A painstaking investigation was undertaken into the prior art in order to establish claims to originality; and, when these claims were found to be justified, the committee was ready to endorse any new method or device and to assist in obtaining for it a fair share of public recognition. This was an expert service welcomed by men who lacked the time or means to exploit the novelty of their ideas; and the committee was never without a number of cases, mostly concerning new industrial products awaiting their turn for study.

The scope of this committee's researches has been remarkably wide. Its approval would not have been so eagerly sought by applicants had not the integrity and ability of its members been above reproach. The high standard of judgment had been systematically sustained by providing a panel of members large enough to ensure that specialists could be chosen to form expert sub-committees. The reports of this committee published in the JOURNAL over a number of years demonstrate the care with which every case was examined and the impartial manner in which the members rendered their judgment upon its merits.

Another factor of their work which should not be overlooked was the encouragement it gave investors. When this committee began its operations, men had not yet learned to invest large sums of money in

such speculative enterprises as the establishment of factories, especially as costs for iron, the essential metal, were high and metalworkers were still scarce. When the Committee had submitted a process, a material, or a product to an exhaustive examination and tests, and had given it their approval, prospective investors had confidence in their judgment and became readier to furnish the funds needed by an inventor. The work of the Committee had removed much of the risk from the investment.

BARTOL RESEARCH FOUNDATION

When World War I broke out, the Institute had neither the staff nor the facilities to undertake research work of the nature required in that emergency, but its educational facilities were taxed to the utmost in the establishment of a school for teaching the newly developed science of wireless telegraphy to men of the selective draft; in administering a recruitment and examination center for applicants for the Aviation Service; and in conducting a school of navigation for the United States Shipping Board.

When that world conflict was drawing to a close, the Institute realized its long deferred hope to have a permanent staff of research workers. In 1918, Henry W. Bartol, a prominent local industrialist, bequeathed a sum approximating one million dollars for the establishment of a laboratory "for the conduct of researches in the physical sciences and for the investigation of problems of a scientific nature arising in the industries."

Actual work did not commence until 1925 in a group of converted dwellings on 19th Street at Race. This site proved to be unsuitable for the purpose and arrangements were made to transfer the laboratories to the campus of Swarthmore College. Here, a building was erected by the Institute where the most sensitive instruments could be installed. Operations were opened in 1928 under the direction of Dr. W. F. G. Swann.

Mr. Bartol had expressed a preference for studies to be undertaken in the fundamentals of electrical science. It is abundantly clear by now that the fields of fundamental research are the incubating grounds for the ideas which supply the needs of industry, and that the older a science grows the deeper an investigator must probe to reach the fundamentals. As regards the fundamentals of electrical science it is impossible to disassociate the electrical concepts from all others bound up with nature's structure, and the student who does research on such a fundamental subject as atomic structure finds that the fundamentals of electrical science are inextricably interwoven in his studies. Before the outbreak of World War II the Bartol Foundation devoted its energies primarily to the study of matters pertaining to atomic structure and to cosmic radiation. Such investigations lay largely within the spectroscopic region and the region of nuclear physics.

With the outbreak of hostilities, the work of the foundation under-

went some modification which has not been without its influence upon its subsequent labors, but the staff is devoting its main efforts to studies of particle nuclear physics; studies of cosmic rays; studies of electrical discharge in gases; and studies of electrical phenomena associated with the solid state. Development of such a program necessitated the building of certain new equipment in line with the requirements of the program. The Bartol Research Foundation now possesses four different types of high energy particle accelerators. One of these machines is comparable to the largest of its type in the world, and a new building has had to be erected to accommodate it and its accessories.

This, then, is an outline of the research work undertaken by The Franklin Institute during the first hundred years of its existence. We are what the experience and actions of a lifetime make us. If this is true of men and women, it is no less true of institutions, and to understand fully a great organization one must know its past and watch its progress of growth and development. During its long history the Institute has passed through a succession of changes in which the pattern of life, both national and individual, has undergone a fundamental change. In spite of violent economic upheavals, mighty wars, and revolutionary discoveries in science, certain characteristics of the Institute's work have remained constant. As other institutions grew and conceptions of responsibility were modified, the Institute relinquished those functions which could be discharged more appropriately in other hands. The tradition of research by team work has survived throughout the changing years.

In the beginning it was necessary to perform only the simplest functions which would enable manufacturers to achieve a position in a swiftly moving economic transition, but large and wider liabilities were voluntarily assumed and supported during the changing years. After equilibrium had been attained, the needs which had to be met were different, new and improved things were constantly sought by industry. Finally, we have arrived at a stage where it becomes increasingly apparent that the choice of what research organizations undertake to do and their capacity for performing their work efficiently are dictating much of industrial policy. The measures which the Institute have taken to adjust its research policies to the needs of the times are reflected in the fully equipped laboratories for research and development which now have been established. The adventure in research which these laboratories afford would provide a technical writer an endless source of material but, as Kipling said, that is another story. Our purpose has been to describe the pioneer work. The Institute laboratories of today are following an ideal set more than a hundred years ago and pursued thereafter consistently by the members. From the beginning it has been recognized that the primary responsibility for all experiment, research, and development is to industry which it serves.

"Water Wings" for Sailors.—Coveralls made of neoprene-coated nylon, a substance which contains petrochemicals, soon may be standard equipment for all submarines to protect personnel. Should they be swept overboard into churning seas, sailors can inflate their "water wings" by pulling a cord that releases carbon dioxide into the life vest. Nylon and synthetic rubber are representative of the myriad products made with petroleum-derived chemicals to aid our armed forces and to contribute to civilian comfort and convenience.

X-Ray Images of Living Organs Shown on Television.—A new medical use for television that opens the door to new diagnostic possibilities was demonstrated recently for a nation-wide television audience. During the program, the actual beating of a human heart was televised and glimpses of other diseased and healthy organs were shown, just as the radiologist views them.

The televising was made possible by the recently completed X-ray image amplifier, a 10-year project of the Westinghouse Electric Corporation. The technique was previously impossible because television cameras were unable to capture the dim image of the fluoroscope. The new X-ray image amplifier overcomes this obstacle by producing a moving image of a person's organs 200 times brighter than formerly possible. Radiologists anticipate that this will make possible simultaneous viewing by specialists hundreds of miles apart.

The program demonstrated the superior effectiveness of the image amplifier in diagnosing different forms of heart disease. Its value in detecting ulcer conditions was also revealed by actually showing an active ulcer.

New Ignition Exciter for Turbo Jet Engines.—A new ignition exciter for turbo jet engines that provides more positive ignition at higher aircraft speeds or altitude has been announced by the General Electric Company's Specialty Transformer and Ballast Department. The unit has been approved for use on four production models of jet engines.

The new ignition exciter, of the capacitor discharge type, delivers energy at constant rate, virtually independent of altitude, G-E engineers said. It requires less average input power, thus releasing more electrical capacity for use without increasing aircraft generating equipment. The unit will deliver rated energy to the spark plug even when input voltages are reduced as much as 50 per cent. This is due to a special stabilizing feature incorporated in the design.

Weighing 3 lb., 4 oz., approximately 25 per cent less than the conventional ignition transformer it replaces, the new G-E exciter produces a powerful, short-duration repetitive ignition spark. A hermetically sealed gap-switch arrangement controls the repeating high-power spark independent of airspeed, altitude, or climatic conditions.

The unit operates from a 400-cycle, 115-volt power supply. It consists of a power source, a storage capacitor, an ionizing transformer, and a "triggering" spark gap. Operating in a range of 50 to 110 per cent of its normal voltage, it functions in minus 55 to plus 125 Centrigrade ambient.

With modifications, the unit is applicable to aircraft heat exchangers, stationary and locomotive gas turbines, and other equipment requiring positive ignition under adverse conditions, G-E engineers said.

RESEARCH—ITS GOAL IN INDUSTRY *

BY

LESLIE R. GROVES [1]

Tonight we are discussing the role of research in industry, and we are doing it in a friendly and understanding atmosphere. This institution and this audience appreciates, I am sure, the spirit of research. It is not necessary, therefore, for me to attempt to give a definition of the word "research." I would like tonight to talk in the main about that part of research which is commonly described as "applied research," for that is the area of most interest to industry.

In our society it is the responsibility of industry to develop the results of fundamental research and to make them available for practical use. The driving force behind this utilization of knowledge by industry is the profit motive. I say this without apology, even though there will always be a few persons in this country and elsewhere who will pretend to see something evil in the capitalistic system.

The results of the profit motive have been to make available for use by the greatest number of people many new machines, new methods, and new materials. These results have raised the standard of living of our fellow Americans and of all mankind. How can the most ardent "do-gooder" object to that?

In general terms it can be said that fundamental research and applied research are complementary. The former wrests scientific secrets from nature: the latter applies this new knowledge to the benefit of mankind.

In the field of industry, research is like a "seeing-eye dog"—these animals are usually quite beautiful to look at, but their real value does not lie in what they look like, but where they are going.

The same thing applies to industrial or "applied" research. We all recognize the value of the pursuit of knowledge for its own sake. But in the industrial field—as distinguished from the field of pure science—we must know what we are doing and where we are going.

Research, like the "seeing-eye dog," must lead us somewhere.

Please do not construe this as a criticism of the value or the motives of pure research. Without a theoretical approach to knowledge, without pure research, we would have very few of the discoveries and developments that have proved of such tremendous value to mankind.

This is simply an effort to place research in its proper perspective as far as its role in industry is concerned. In the industrial field, applied

* Address delivered at the Stated Meeting of The Franklin Institute, April 15, 1953, in the Lecture Hall.

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research is the direct outgrowth of fundamental research. Industrial production must ultimately benefit from the efforts of theoretical science; and it follows that without the economic fruits of industrial production, we would have little to support our research laboratories.

This partnership is more than a working agreement. It must be highly coordinated. There must be constant team-work for each of the partners to achieve the full results. Later in this discussion I will take up certain methods by which this partnership can be made effective. At this point, I wish merely to emphasize the *dual* nature of the research team. Recent figures show that the national outlay for industrial research in 1951 was more than three and a half billion dollars. Two thirds of this sum was spent in laboratories owned or operated by private industry.

During the early years of World War II, I was assigned, as many of you know, to direct the Manhattan Project, which produced the first atomic bomb. The investigation of the atom's energy was an example of a kind of pure research that was started—if not aimlessly—at least with no definite industrial or useful objective. As it developed, however, its implications increased. Before the second World War, research on nuclear fission was purely scientific; but when war broke out in Europe, this research became a practical necessity of war. What had been an activity in the realm of pure science, because no utilitarian objective was in view, suddenly became a military project, aimed at winning the war. In other words, it was *applied* research.

Even before it had achieved its military purpose, we began to re-examine the research and to direct it toward industrial purposes. Perhaps nothing in modern knowledge more aptly illustrates the point I made at the beginning of this discussion, than the brief history of the research into atomic energy. This refutes the argument, so often made, that pure science and applied science cannot be harnessed together in a team. In this case, the scientists who were working on the theory of nuclear fission as a source of energy needed to have a target set by the war needs and their efforts redirected toward this goal.

I shall deal with this subject in greater detail later; but I mention it now to indicate how vital it is not merely to initiate research into any problem of science or industry; but also to harness it. Sometimes by a lucky accident an aimless bit of pure research develops into something of great practical value; but this is the exception, not the rule. Our interest must be primarily in planned research, following a predetermined pattern, with anticipated results.

This view may sometimes be at variance with the motives of the research scientist himself. He may become preoccupied with the mere pursuit of a problem, following it through a chain of experimentation until he has reached a conclusion. He may become more interested in knowing about things than in knowing what to do with them. This may be a noble purpose, but unfortunately, it is seldom a useful one.

This variance in viewpoints at times requires a management decision that is heart-breaking to the scientist. It may mean scrapping labors of weeks and months—even of years—when a changed situation in industry, or in our economy, makes the original objectives obsolete. The scientist in industry must conform to the principle of utilitarianism.

This imposes upon our industrial research organizations a requirement that is more familiar to the auditor or the accountant than to the scientist. I refer to the *financial* responsibility. Research activities must be controlled *vigilantly* and *continuously* to be sure that we are still aiming our work at a useful objective. We must exercise a moral responsibility not to science, but to the business or industry we serve.

This attitude may be disturbing to some men, whose lives are devoted to acquiring knowledge; but it is the only practical attitude we can assume in the field of industrial research. In business, we are custodians of other people's money; and unless we spend it in such a way that our business will make a profit, we will not be kept very long as custodians.

I have made this point at the outset, because in discussing this subject of the role of research in industry, we must keep our eyes on the basic objective which is to turn out better products, and make them at a profit. We have to leave to institutions devoted to pure science the pleasure of making things just for the fun of making them. In industry, we are not concerned with projects in scientific research unless we can do something with the results that will help make better products, or make them cheaper or faster.

This brings us down to the basic starting point of industrial research. How much of our time and money and manpower can we afford to devote to practical industrial research?

There is no fixed rule of thumb, of course, that can tell us what proportion of a company's earnings, for example, should go into research. There are many conditions varying with the kind of product and the need for developing it. The research needed to improve the legendary mousetrap—which some philosophers erroneously have assumed can stimulate great migrations of mankind—differs considerably from the research needed for developing a typewriter, or an electronic computer, or an airplane.

The role of research must be computed in dollars as well as in results. Surveys have shown that about two per cent of the annual gross revenues of industrial concerns in this country are put into research and development. The amount of research money spent will vary, as I said, with different industries. For example, in 1951 the aircraft industry spent approximately thirteen per cent of its gross revenues for research; in the electrical machinery and instrument industries the percentage of money spent was about half that figure. These industries, it may be noted, were engaged largely in defense contracts and thus were spurred on by a greater urgency than would normally be the case. The average

in 1951 was two per cent, and many industries spent much less than that.

We have defined the role of research in industry, as opposed to—or rather differing from—its role in theoretical science. What are the purposes of research in industry?

We can list the principal aims:

1. To improve the quality of products already in use.
2. To develop new products, materials or processes for use in markets that already exist, or for new or potential markets.
3. To develop new uses for existing materials, processes or products.
4. To reduce production costs.
5. To work out "bugs" that have developed in products or processes.
6. To standardize products where uniformity is an economic asset.

There may be other basic aims, but these include most of the important reasons for industrial research. They represent, in each case, a *useful aim*. They will bring us more products, better products, and cheaper products. And it is important to note that in our economic system, as distinguished from other economic systems, these aims are the natural objectives of competitive economy. They represent the ideals of the American way of life, and the American industrial system.

As may be supposed from this summary, the real purpose of industrial research is to make more money. We know from experience that the profit motive indirectly supports all the sociological motives we may have. It gives us more products, and better products, at less cost than any other system in the world today.

However, there are degrees of concentration upon this primary purpose. To some people, making money is getting what they can get while they can get it. This is quite different from what I believe should be the basic philosophy of industrial research.

By its very nature, the objectives of industrial research must be long-range. There was a time in our economic history when this was not the prevailing philosophy. Frequently the objective was to get it, and get out. We have found through some rather bitter experience that this is a short-sighted policy. The large industrial organizations of this country today are laying out vast sums for research that may not realize the full fruits of economic growth for years. But we know that a company cannot stay in competition unless it meets this challenge—unless it prepares for long-range growth through research that may have no immediate productive benefits.

Management has had to take the position that research cannot be measured purely on a basis of immediate profit—that is, of dividends today. It must be measured from the standpoint of competition, expansion, and survival. One of the most delicate problems that management faces today is the proper estimation of the balance between profits and survival, in its appraisal of its research program.

Research is essential to growth. The results do not go directly into the individual product, but into the company itself. And we must also consider the total expense required to put the results of research into successful and efficient production and distribution. It may cost only a million dollars to complete the job of improving a product; but it will cost ten times that much to tool up for the new production, to increase working capital, advertising, sales promotion and sales—all the things that are necessary to put the product into efficient use, once the research project has been completed.

The problem of financing an industrial research program today has been complicated by many factors including the government's tax program. As I pointed out before, industrial management is working for the stockholder and must be very careful that good use is made of the money at its disposal. The problems of justifying expenses are further complicated in respect to a research program because the aims and results cannot be broadcast to the myriads of stockholders until they are accomplised and are on the market. It is sometimes extremely hard, therefore, to justify the steadily increasing research expenditures against the need for paying reasonable dividends.

The balanced organization must take into account the proper allocation of the financing of research. There are two main factors involved: first, the amount of working capital that can be allocated for research; and second, the amount of invested capital which may be available. While the research budget cannot be exactly determined in advance—since there is no way of anticipating the actual cost or extent of certain operations—by dividing the expenditures and allocating the research money properly, the company can build a research program that fits into its financial picture.

If this kind of planning is undertaken, a company will be able to develop its research facilities without the great waste that often makes haphazard, short-range research an impossible burden upon its financial structure.

It is well known that research creates wealth, but if it is not fitted to the financial capability of the company, even the most competent research can become futile and may even bring about the financial collapse of the company itself.

The cost of fundamental research, whether direct or indirect, is really borne by industry. By far the major proportion of all college and foundation money has come either directly or indirectly from industrial profits. We also have a growing source of support for this fundamental work from the government. The government money also comes from industry, and the government developments go back to industry. The government program is less efficient than an industrial program but the rules and objectives are much the same. The changing emphasis in our economy in the direction of more and more government

money has led us into a fallacy of thought that the government is supporting large amounts of fundamental research. In reality, this government research is aimed at more specific goals than industrial research and is invariably administered by government bureaus with a shorter over-all planning.

With respect to military improvements, I believe the government must support such programs because the potential return to anyone but government is so slight.

The best example of this is the atomic energy program. You are all familiar with the magnitude of this project and realize that it took a combination of many of our largest industrial corporations to make it a reality. Without government backing or underwriting, it is inconceivable that this group of corporations could have made such a project possible. It is interesting to note that the atom bomb project, which is the largest research and development program that has ever been done, is a typical example of all I have discussed this evening concerning an industrial research program. The problems that were met are exactly the same as those that we have met in such private industrial programs as building the UNIVAC. The proportion of fundamental research is the same; the handling and shortage of personnel is identical; and the relative ranges of cost between the research program and the money necessary to put it in production are the same. The only possible difference arises from the time scale that was dictated by necessity. In the atom bomb project we followed in parallel all the different approaches that we thought might turn out to have a reasonable possibility of success. In industry we tend to select one or two possible approaches and spend more time analyzing their possibilities beforehand. This, however, is only the general rule and where extreme haste is warranted, we follow the same pattern as the atomic bomb project.

The actual organization of a company requires a proper integration of these research functions in the corporate chart. In one company, which has extensive research requirements, the laboratories are organized so that a section is assigned to fundamental research, where the technical staff works in an unhurried, unscheduled atmosphere, under congenial surroundings which stimulate the kind of thinking necessary for success in this area of research activities. Other sections devoted to applied research are located separately, in closer conjunction with the production end. The applied research staff does not look to the pure research staff for solutions to its problems, since they do not receive the results of pure research until it is completed. Thus, both staffs function within their areas, and the result is an efficient and planned organization, with adequate communication between the different levels of research, but not an encumbering and confusing mixture of both.

Human nature is such that we all like to see concrete results from our work. One of the greater rewards is recognition of accomplishment.

For this reason, you will find that all fundamental work is really done with the hope that it will be useful to someone else. Because of the retiring nature of most fundamental researchers, they tend to hide behind a cloak of doing research just for the sake of research. In actual practice, however, it does not work this way. The research worker is invariably willing and anxious to accomplish something concrete. He may be working further back than most directly supported industrial research and at the same time possess a vision in his field that is far ahead of contemporary thinking.

We now come to the next phase of research planning. We have not merely a partnership between fundamental research and applied research, but a three-way partnership which includes applied research, production and distribution. Therefore, in point of chronological development, one of our first steps must be market analysis.

At this point it is easy to see that we have gone far beyond the realm of "pure" scientific research. We have, in a sense, embraced the entire economic system. The development may be charted in this way:

1. Fundamental research and exploratory research.
2. Applied research.
3. Development.
4. Production.
5. Distribution—that is, market analysis and sales promotion.

Obviously, it is impossible to render at the starting point an advance accounting of the cost-and-returns phases of research financing. We must allow for margins—for expensive failures, if you will. But in the final accounting, research must "pull its weight" in the boat, or something is wrong with management.

While it may be impossible to project a complete market analysis before a product has been invented, developed and produced, it is necessary to form some estimate of the potential market before money is spent in research and development, and in tooling up for production. Therefore the research end of the industrial system must be integrated with production and distribution—in the full partnership to which I previously referred.

This partnership may start out as a honeymoon, but it often changes into the complex problems that are more familiar to married men than to bachelors. It takes one type of mind to engineer a product, and another kind to produce it, and a third kind to sell it. Sometimes there is no meeting of minds at all. The research engineer accuses the salesmen of lacking imagination at one point, and the next minute he charges him with having too much imagination. The salesman blames the engineer for building something he can't sell.

The human factor cannot be ignored in this relationship, and it is the job of top management to resolve these inherent difficulties. When

management itself is not properly balanced, one side or the other may gain a predominant position, which is extremely unhealthy for the entire organization.

There is no fixed pattern for this kind of relationship. Each project must be treated according to circumstances involved and the nature of the work. But experimentation and fundamental research must be harnessed together to provide the results that will be useful for further applied research on an industry level.

In the past a great part of our development in Remington Rand was mechanical or electrical. This is changing, however, with new developments in electronics. In the case of the business machines industry, in which we are engaged, a large proportion of the mechanical development took place some years ago. Methods of calculation grew up in this way, and the older mechanical engineer today relies upon his experience in this field.

However, there is a great change now in progress, stimulated to a great extent by the requirements of aircraft design, with the constant need to reduce weight which required the development of very exact and refined mathematical calculations of stresses, vibrations and inertias.

The development stage in industrial research brings up one of the most difficult management jobs in the whole program. Whether we like it or not, we are continually working primarily with individuals, and human nature is such that each individual, particularly in a research or engineering group, has his own ideas. The problem of welding these varying ideas into a common sensible goal is much the hardest direct management job that we have. I think we have proven time and time again that a product must go through several levels of engineering before it is ready for production release. A man who has the original brilliant concept of something new is invariably a poor man to carry it through to a final stage of completion. The different—although equally valuable—mentality that can complete a project, seldom produces the basic concept. As these two phases require different men with different kinds of thinking, it would be reasonable to expect that they would respect each other and work well together. This, however, in practice, is not the case. You will continually hear the engineer who is assigned to put someone else's original conception model into shape say, "Doesn't that group ever learn that we have to produce these things?" Interestingly enough, this is exactly the same comment that is made by the production department when they receive the model in the next stage. This, in one sense, is healthy. Each man realizes that he has a definite job to do but, unfortunately, this attitude tends to carry too far.

The great danger comes from a desire to make changes seemingly just for the sake of making a change, and unless this phase of the operation is very carefully controlled, the changes will get completely out of hand. There is no formula that I know of for controlling this situation

other than close technical contact with the individual project. Without this contact or some system of following through, no development project will be successful. It is impossible to assign someone to this job and have it done adequately. A man who can perform these functions must be able to do it entirely on a basis of mutual respect with the various engineers concerned.

While I have touched on the problem of research personnel, particularly as to the relations between research engineers themselves, and relations between the research group and production and sales groups, there is an over-all problem of personnel that should be stressed.

It has been said that the employment of mediocre research personnel at low salaries, rather than top-flight personnel at high salaries, is "penny wise and pound foolish." Like most generalities, this one needs a closer inspection. The mere paying of high salaries obviously does not create a top research man. But the problem of getting and keeping top men is still one of the most harrying of all the problems that confront a research program. In my opinion, a specific effort must be made by industry to interest good men in research work, and to train and develop more research engineers for the constantly expanding programs that lie ahead.

It is also a mistake to mix the administrative functions with the scientific functions of good research engineers. The top scientific men should be used for the jobs they are best qualified to hold—that is, the research jobs. Administering a research staff is similar to the administering of any other business staff, and technical skills are often of little use in administrative activities. The head of a research organization must be competent technically if he is to be successful.

As I have said, the most complex and dramatic research project of our time has been the development of the atom bomb and atomic power. I should like to emphasize at this time a point that I have made on previous occasions. That is: the application of our atomic energy research to industrial uses must take second place to the use of atomic energy as a military force.

This country has survived the tensions of the "cold war" that followed the end of World War II for one reason and one reason alone: we are still leading in the world race for development and production of atomic bombs. Russia's current peace offensive might even be based on her knowledge that we do possess this superiority.

The atom bomb has protected us. It has ended one war and has enabled us to avoid a world conflict which we might otherwise have been unable to avoid. But the atomic bomb can destroy us, and it can destroy civilization as we know it. Until there is a definite and decisive plan that will control the use of the bomb, we cannot afford to relinquish this superiority we now possess in producing the bomb.

In my opinion, it is not inconsistent with this policy to promote the

use of nuclear energy for industrial purposes as long as such use does not involve security risks. There are many ways in which industry is already using the by-products of atomic energy research, such as the use of radioactive isotopes in instrumentation and in medicine.

Just last week it was announced that the White House has made the first official move towards modifying the Federal monopoly on atomic energy. It proposed that private industry be allowed to finance and run its own atomic-powered plants.

This is what we looked forward to most hopefully even before the completion of the bomb. If it can be accomplished without risking the loss of superiority we now have over Russia in the development and production of atomic explosives, I am heartily in accord.

However, there are two major problems involved. One is that of maintaining proper security control of the knowledge which must necessarily be placed in the hands of organizations and individuals. The other problem involves the supply of fissionable material needed for the protection of our country.

I do not know just how the necessary safeguards to protect vital national defense secrets can be maintained. Certainly it would not be an easy task. Those who feel that it would be simple seem to ignore the fact that mankind is not perfect. They seem to ignore the facts of life. We still have penitentiaries. We still have traitors. And most dangerous of all, we still have men of apparently high intelligence with blind spots. These men feel that their judgment is supreme, even on matters that can affect the security not only of their fellow-countrymen but of the entire world. Let us not forget that this was apparently the attitude of the two English scientists involved in the disclosure of vital information on the atomic bomb. And let us not forget that their supposed views have received a great deal of sympathy from others, in England and in this country. And let us not forget that we have had our Alger Hiss and the Rosenbergs. Moreover, it is only reasonable to assume that for each one discovered there have been others who have not been detected. Do not forget that it is impossible to protect from embezzlement the knowledge which is in the head of an individual and it is almost impossible even to detect the embezzlement itself when the knowledge is passed from the embezzler to a foreign agent.

Unfortunately, our very liberties aid and protect the traitor. The Fifth Amendment to the Constitution of the United States reads in part: "No person shall be compelled, in any criminal case, to be a witness against himself." It has been invoked on numerous occasions during these past few months by persons who have not wished, either through fear of incrimination or plain perversity, to answer the question of legally constituted investigating committees or of the courts. The judicial interpretations which have been placed on the Amendment have been such as to lend great aid and comfort to anyone engaged in espion-

age activities. To me, it is one of the tragedies of our present situation that these interpretations have been stretched so far that the country is unable to protect itself against those who would betray it.

Please do not misunderstand me. I believe very definitely that private industry should be allowed and encouraged to take fullest advantage of atomic development, but only to the extent that such advantage will not injure the military security of the United States. Since the beginning of time mankind has faced a conflict between a desire for a higher standard of living and a desire for security. Primitive tribes and civilized nations have been faced equally with that problem. In modern times we have seen what has happened to countries which neglected their security in favor of easier ways of living.

Our cliff-dwelling Indians learned centuries ago that it paid them to build homes in cliffs, safe from raiding enemies. I imagine many an Indian woman must have regretted this fact as she carried her water jars sometimes for miles from the river in the valley up to her dwelling in the cliff. But if they lived near their irrigated corn fields they were doomed to death and destruction. Those tribes which paid for security were the ones that survived.

I feel that we can develop atomic power for industrial uses without impairing too greatly our superiority through the disclosure of vital information. But I believe that it will be a most difficult task. The control of methods of safeguarding information must be in the hands of men who are sympathetic to such safeguarding. It must not be in the hands of men who feel that we owe the world all possible knowledge, and where mistakes may become national barriers to security and peace.

One of the great difficulties in the control of knowledge in the atomic power field is that much knowledge essential to the efficient production of fissionable materials for atomic weapons will have to be known by many people. We had 600,000 employees on the atomic bomb project at one time. The known number of traitors could be counted on your fingers. But one man, Dr. Fuchs, was able to give more information on the subject than could have been given by hundreds of thousands of the others put together. And yet Dr. Fuchs was, as you probably know, definitely vouched for by the British Government as to integrity, loyalty and trustworthiness. And as long as he was in this country, he gave no indication that he was not entirely trustworthy.

It is not possible to guarantee that every man out of thousands and tens of thousands will be entirely reliable. The more people who know a secret, the less it is a secret, and this is as true in atomic affairs as it is in the average women's sewing society or in the locker rooms of your golf clubs. No matter what we do the decision must be governed by the need for this country to maintain its superiority in the atomic field, if it is to retain its military strength and to remain alive. Let us never forget that.

Radioactive Water Aids in Food Processing (quoted from R. R. Baldwin's remark's in "Atomic Energy in Industry," recently released by the National Industrial Conference Board).—Radioactive water has been used in dehydration-hydration studies and drying studies on food products. The processor is frequently interested in the degree and rate of water penetration into food products. This determination is difficult if not impossible by ordinary chemical means. Of course, an ordinary moisture determination will tell you how much water is present, but it will not tell you where the water is in the food product. However, using radioactive water, it is possible literally to take a picture of the water distribution at any stage of the process.

Radioactive water is also of considerable use in evaluating new packaging materials. The food manufacturer is usually interested in keeping moisture out of his packaged materials. Moisture diffusion rates through packaging materials may be measured conveniently by tracer techniques making use of radioactive water in vapor form. I might add that the conventional methods of measuring moisture diffusion rates are difficult and time consuming.

Electronic Circuits on Cloth.—A new method of producing flexible electronic circuits, as contrasted with the rigid etched or stamped circuits, was described by E. R. Bowerman and R. F. Walton of Sylvania Electric Products Inc., Bayside, N. Y., at the annual National Conference on Airborne Electronics sponsored by the Dayton Section of the Institute of Radio Engineers. The new flexibly mounted circuits consist of thin layers of copper, in the desired configuration, attached to a woven cloth by a thermosetting adhesive. One of the important advantages of the flexible circuit is that it may be attached to rigidly fastened components whose connecting terminals may have large dimensional tolerances, according to Bowerman and Walton. An appreciable amount of dimensional differences between units may easily be taken up by the flexible backing of the circuit.

The production of the flexible plated circuit consists in silk screening an insulating lacquer in a suitable pattern, onto a stainless steel plate, copper plating the exposed areas of the steel, and stripping the plated copper and the insulating lacquer from the steel surface by an adhesive tape. The plated copper and lacquer are stripped from the steel plate by pressing firmly and evenly an adhesive tape of suitable area over the circuit and then giving it a rapid, continuous pull. The thermosetting adhesive may be cured by heat, or it may be allowed to cure in the equipment in which it is installed, they continued.

Bowerman and Walton pointed out that because any markings in the steel plate will be faithfully reproduced in the copper, identifying marks may be placed in the circuit by etching, engraving, or sandblasting appropriate symbols into the steel plate.

Low Viscosity Lubricant Helps Reduce Radio Noise.—In an investigation of radio interference caused by antifriction bearings in rotating equipment, the Naval Research Laboratory of the Office of Naval Research has determined that noise can be minimized by use of a low-viscosity lubricant, such as a light petroleum oil or grease. However, the laboratory also states that in the design of new equipment insulating sleeves, insulating bushings or shafts of nonconducting materials should be used wherever practicable.

WIND EXTREMES AS DESIGN FACTORS *

BY

ARNOLD COURT [1]

ABSTRACT

Wind varies so rapidly in time and space that arbitrary decisions must be made as to the strongest wind for which structures should be designed. From physical and statistical considerations, it is recommended that small, portable structures (such as tents) be designed for the strongest winds likely to occur once in 20 years, in any except extremely windy areas, at 10 ft. above the ground for a 5-min. period, and for 1-sec. gusts which are 50 per cent greater than this figure. In addition, auxiliary means (for example, tie-down ropes) should be provided to withstand the strongest winds likely, with the same qualifications, in extremely windy areas.

The strongest wind likely in 20 years is chosen to insure a probability of no more than 10 per cent that a greater wind will occur within 2 years and thus cause premature failure of the structure. Analysis of the strongest 5-min. winds in each of 37 years at 25 places in the United States, selected for constancy of anemometer height over that period, shows that a valid wind speed for the design of such small structures is *40 mph. for 5 min., with gusts to 60 mph.*, and that facilities should be provided to permit the withstanding of winds of 60 mph. for 5 min., with gusts to 90 mph.

PROBLEM

The strongest wind which a structure or piece of equipment may encounter, and for which, therefore, it should be designed, is most difficult to determine. No other climatic element varies as widely and rapidly in time and space, both horizontally and vertically, as does the wind. Since none of the many estimates of the "design wind" has proven fully satisfactory, this report presents a new evaluation, intended primarily for small structures such as tents or machinery trailers, whose over-all life expectancy is only a few years. The methods developed, however, can be applied to larger structures and for greater lifetimes.

Wind is "the movement of air" or "air in motion," generally in a horizontal plane but with some vertical components as well. The force or pressure which it exerts on an object in its path is proportional to ρv^2, the product of its density, ρ, by the square of its speed, v. But its power, or rate at which it works, is proportional to the product of this pressure and the distance over which it acts in unit time, or ρv^3.

Stationary objects are affected primarily by the pressure, but those which move in the wind are affected by its power. Thus a rigid flagpole must withstand the wind's pressure, but its flag whips around in proportion to the power, or cube of the wind speed. Similarly, although the

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strength required of a rigid structure depends on the square of the wind speed to which it may be subjected, the durability necessary for loose tent canvas varies with the cube of the expected wind speed.

Wind speed generally increases with height above the surface of the earth. The rate of increase is greater over smooth ground than over rough, and greater when temperature increases with height than when upper layers are much colder than those at the surface. For the ratio of wind speeds v_1 and v_2, at heights z_1 and z_2, the older formula (1) [2]

$$v_1/v_2 = (z_1/z_2)^a$$

has been superceded (2) by one due to Thornthwaite and Halstead (3):

$$v_1/v_2 = [\log (z_1/z_0)/\log (z_2/z_0)]^{1/p}.$$

The exponent p varies from about 0.5 under very stable atmospheric conditions to about 2.0 when the lapse rate is superadiabatic and turbulence is strong. The constant z_0 is in effect the thickness of the surface film of calm air. It varies with the temperature, and also with the nature of the ground surface, and possibly other factors. It is estimated (4) at 0.07 ft. under stable conditions, 0.4 ft. under turbulent conditions.

With $p = 2$ and $z_0 = 0.4$, applicable when winds are strongest, this formula shows that the ratio of the wind speed at height z to that at 10 ft. (the height of a small portable structure) is

$$v_1/v_{10} = 0.85\sqrt{\log_{10} 2.5z}.$$

For various heights, this ratio is:

Height in feet:	2	5	10	15	25	50	75	100
Ratio to 10-ft. wind:	0.71	0.89	1.00	1.07	1.13	1.24	1.29	1.32

This computation assumes that the wind speed at any height, under gusty conditions, is proportional to the square root of the logarithm of that height. Since wind force is proportional to the square of the wind speed, the force exerted by a strong wind increases as the logarithm of the height above ground, while the power increases as the 3/2 power of the logarithm.

Thus any estimate of the strongest wind likely to be encountered by a structure or piece of equipment must be made specifically for the actual height of exposure. Basing the design of a small toolshed on the strongest wind observed on top of a tall building will lead to over-design. Guying a radio tower for winds no stronger than those observed at 15 or 18 ft. above the ground may be disastrous.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

MEASUREMENT

Winds are rarely steady—they fluctuate in speed from minute to minute, even from second to second, by appreciable amounts. Although the speed for a fraction of a second can be measured by laboratory-type apparatus, such as hot wire anemometers, the conventional instruments determine the speed over a period of seconds or even minutes.

Wind speed usually is measured either by the rate of motion imparted to a freely-rotating mechanism, or by the pressure effect. Rotating anemometers, whether horizontal (cups, hemispherical or conical, on arms or a wheel about a vertical axle) or vertical (propellors turned perpendicular to the wind by a wind-vane mechanism), essentially measure wind passage. Large cup anemometers often have dials indicating the cumulative wind passage, in kilometers or miles, or fractions thereof. In addition, the rate of passage usually is indicated by combining a timing mechanism with the anemometer. Contacts closed at each unit passage may allow an electric current to flash a light or activate a buzzer so that an observer may count the number of passages in unit time interval while watching a clock. More elaborately, the current at each contact closure may cause a pen to move on a clock-driven chart, or permit one electric condenser, which is charged at a constant rate, to discharge onto a second, from which the rate of leakage indicates the wind speed on dial or chart. In another system, the anemometer rotation is imparted to an electric generator whose voltage and frequency are proportional to the wind speed.

Pressure anemometers do not indicate wind passage, but "instantaneous" speeds which are actually averages for about one second on the instruments in general meteorological use, although the intervals may be much smaller in laboratory-type equipment. Pressure may be measured by the torque applied to a set of cups mounted on a horizontal wheel bridled by a spring, by the force on a vertical plate held perpendicular to the wind, or by the difference between pressures in tubes opening into and across the wind (Dines anemometer). These pressure effects, through suitable linkages, may be shown as wind speeds on a dial or recorded on a clock-driven chart.

The first international agreement on the time interval represented by a wind observation was the specification by the International Meteorological Organization, in 1947, of a 20-min. average for wind speeds in synoptic reports. This was already the practice in some countries, and others have adopted it since. But synoptic reports of the U. S. Weather Bureau, which formerly contained average 5-min. speeds, now contain (5) 1-min. estimated averages from direct-reading pressure (bridled cup) anemometers, where available; otherwise 5-min. averages, from rotation cup anemometers yielding a record ("triple register") of each mile of wind passage, are used.

For climatic purposes, in the United States as in most other countries, the total wind passage in each hour is obtained from recording instruments at the principal weather stations. These hourly speeds are averaged to give daily, monthly, and annual figures. However, at stations without records of wind passage, that is, stations with only pressure anemometers or non-recording rotating anemometers, the corresponding climatic figures are based on the hourly or other periodic visual readings. This practice may introduce a rather large sampling

error, since the period of observation is neither truly random nor exactly fixed.

DURATION

In addition to average speeds, summaries usually list the greatest speeds over various time intervals, which differ from country to country, and even from station to station. In the United States, extreme wind values tabulated for each day, month, and year are:

Maximum speed: greatest average speed over a 5-min. interval;
Extreme speed: speed of fastest mile of wind, from record of rotating anemometers only;
Strongest gust: highest reading of "instantaneous" recording anemometer (pressure, pitot-tube, or bridled-cup).

From two studies (6) of the records for Washington, D. C., one of the few places where cup and pitot-tube anemometers operate side-by-side, it appears that during any period with speeds above 30 mph.,

1. Strongest gusts are about 1.4 times the extreme wind (fastest mile).
2. Strongest gusts are about 1.5 times the maximum speed (5-min.).

These rough relationships appear to be borne out by the more detailed data from a later investigation (7) which, although not fully analyzed, indicate that extreme speeds are about 1.09 times the maximum speeds.

Thus wind speeds, especially strongest speeds, reported from various places or for various years at the same place cannot be compared rationally without full information on the method of measurement: height and exposure of anemometer, type of anemometer and record, and interval covered by the measurement. Unfortunately, these details are rarely given even in complete climatic discussions, despite their importance to the user of the data.

In choosing the strongest wind speed for which a structure or piece of equipment is to be designed, the time interval over which the wind is measured must be specified. Both instantaneous gusts and sustained strong winds have important design aspects. The impact of a severe gust may impose a greater load on a rigid structure already strained by a strong, steady wind than it would when the general wind is lighter.

In addition to the duration of a strong wind, its vertical and horizontal extent must be considered. This aspect of winds has been studied most completely by Sherlock and Stout (8), using extremely sensitive and accurate pressure-plate anemometers mounted atop a string of twelve 50-ft. poles spaced 60 ft. apart, and also at 25-ft. intervals on a 250-ft. tower. Their investigations, however, were confined to "winter storms," chiefly strong cold-front passages across lower Michigan.

From their detailed graphs of wind speeds at half-second intervals, it appears that in the strongest gusts the peak speed is attained through-

out a core about 20 to 60 ft. wide at the 50-ft. level. While the speed of such gusts must be considerably less at lower levels, no information is available on horizontal extent of these peak speeds at, say, 10 ft. above the ground. The horizontal gradient of maximum wind speed must depend on the dimensions of the system causing the wind; obviously the gradient is greater in intensely local storms, such as tornados, than in large-scale circulations such as hurricanes or extra-tropical cyclones.

Except for tornados, which are excluded for consideration for reasons given later, the strongest wind at any height near the ground may be assumed to occur simultaneously over distances as great as 50 ft. Consequently, a small structure must be designed to withstand a specified strongest wind acting simultaneously over the entire lateral extent of the structure, at the structure's height.

For tents, portable buildings, vehicles, and similar structures and equipment items, a design height of 10 ft. appears adequate. Thus the "design wind" may be taken to be the strongest wind over a 5-min. period expected 10 ft. above the ground, accompanied by a 1-sec. gust exceeding this value by 50 per cent. A more precise definition of "expected" is attained in the next section.

FREQUENCY

An event, such as a wind speed exceeding a given value, which occurs in H trials (years) out of N has a *relative frequency* of H/N and an *apparent return period* of $T = N/H$. If the recurrence of the event depends on so many independent factors that it may be considered to follow the laws of chance, the observed or relative frequency comes closer and closer to the *true probability* of occurrence as the number of trials (years of observation) increases. Similarly, the apparent return period comes closer and closer to the true return period, which is the reciprocal of the true probability.

The true return period is therefore the *average* of all the intervals between recurrences of the event in a very long series of trials (years). However, for an event whose true probability is small, the binomial distribution of the intervals between recurrences approaches, in the limit, the Poisson distribution of statistics: the probability that an event whose average return period is T *will not occur* within $T/r = N$ trials (years), that is, the probability that (x_N), the largest value observed in N trials, will be less than (x_T), the largest value occurring on the average in T trials, is

$$P(x_N < x_T) = (1 - 1/T)^{T/r} \xrightarrow[T \to \infty]{} e^{-1/r}.$$

Thus half of the intervals between recurrences will be less than 0.693 of the true return period; this is the *median interval*. And more recur-

rences will come in the year following an occurrence than after any other given interval; that is, the *modal interval* is 0.

For a wind whose return period T is greater than 10 (so that the Poisson approximation is valid), the number of trials (years) within which recurrence is likely, can be expressed, for various probabilities, in terms of percentages of the return period:

Probability:	0.10	0.20	0.25	0.30	0.33	0.40	0.50	0.63
Per cent of T:	11	22	29	36	41	51	69	100

Thus there are two chances in ten that an event (such as a strong wind) will recur within a period which is only 22 per cent of its true return period. For events with return periods shorter than ten years, the percentage figures are somewhat smaller. For $T = 2$ years, for example, the percentage is 10 for a probability of 0.10, and 58 for a probability of 0.50. Such figures, however, have little meaning, because the return period is computed to the nearest year, and estimating probabilities in terms of fractions of a year is not justified.

These probabilities can be converted readily into terms of calculated rsik. For any *desired lifetime*, it is possible to compute the *design return period* whose corresponding event has no more than a given probability of occurring within the desired lifetime. The per cent of the desired lifetime which will give the design return period (T_d), for various calculated risks, is (for $T_d > 10$):

Calc. Risk, U:	0.63	0.50	0.40	0.33	0.30	0.25	0.20	0.10	0.05
Per cent of T:	100	144	196	247	280	345	448	949	1950

Thus, a building which is to last 20 years, with a calculated risk of 10 per cent that it will not fail due to strong winds in less than that time, should be designed for the strongest wind likely to occur in 9.49×20 years $= 190$ years. For a desired lifetime of only 2 years, the percentage factor is 171 for a 50 per cent calculated risk, 975 for a 10 per cent risk; that is, the building should be designed for the strongest wind likely to occur in 3.4 or 19.5 years, respectively.

These findings can be incorporated into the design criteria previously developed: the design of small structures should be based on the strongest wind, over a 5-min. period, 10 ft. above the ground, likely to occur in 20 years, and on gusts which are 50 per cent greater. This provides a calculated risk of 10 per cent that the structure will be blown down in 2 years, 20 per cent in 4 years, 30 per cent in 7 years, and 63 per cent in 20 years.

EXTREMES

Determination of the strongest wind likely to occur in 20 years, or any other period, requires a statistical evaluation of observations to estimate the true probability of occurrence of winds of various speeds

From this probability the true return period is obtained. If the occurrence of strong winds does depend on so many factors that it can be considered to follow the laws of chance, then the observed relative frequency based on a relatively short period of observation may differ markedly from the true return period.

An event which has occurred once in 50 years has an observed relative frequency of 0.02, but the true probability of occurrence may be either greater or less. In this case, the best that can be said about the true probability (9) is that there is 95 per cent confidence that it lies between 0.00 and 0.11.

However, if the strongest winds observed in each of the 50 years are analyzed statistically, a much more precise estimate of the true probability, and thus of the true return period, can be made. Methods for such a statistical analysis are provided by the theory of extreme values as developed by E. J. Gumbel (10, 11). Extreme values are the largest (or smallest) values in each of a series of samples from the same general population, or group of things. The strongest winds observed, at the same place, in each of several periods of time (months or years), are such extreme values.

The theory of extreme values assumes that there is no relation or dependence of the extreme of one sample on that of another. Since storms may last more than one day at a time, the strongest winds of each day would not be expected to follow the theory as well as the strongest winds of longer periods. In general the wind strength varies through the year in a rather constant pattern (the windiest month (12) is December or January along the coasts, March or April over much of the interior of the United States). Thus the strongest winds of each year may be analyzed by the theory of extreme values.

According to this theory, the strongest wind likely to occur in T periods (years) is

$$x_T = \bar{x} + Ks_x.$$

Here $\bar{x}$ and s_x are the mean and standard deviation of the highest winds observed in each of N periods. K depends on N and T, respectively the number of years of observation and of years for which the estimate is desired.

Values of K, for various values of T and various periods of observation N, are:

Years Observed, N:	15	20	25	30	40	50	70	100	200
K for T = 20 yr.:	2.41	2.30	2.24	2.19	2.13	2.09	2.04	2.00	1.94
K for T = 50 yr.:	3.32	3.18	3.09	3.03	2.94	2.89	2.82	2.77	2.70
K for T = 100 yr.:	4.01	3.84	3.73	3.65	3.55	3.49	3.41	3.35	3.26
K for T = 1000 yr.:	6.26	6.01	5.84	5.73	5.58	5.48	5.36	5.26	5.13

These values permit determination of the strongest wind likely to occur in 20, 50, 100, or 1000 years, if the strongest speeds in each of

many years (N) are available. Values of K for other values of T and N are tabulated elsewhere (13).

DISTRIBUTION

Selection of extreme wind data for analysis by the theory of extreme values, in order to determine the strongest wind for which structures must be designed, requires careful consideration of the distribution of windiness over the earth.

The strongest winds in the world are those of tornados, which are most common in central North America. For the United States as a whole, an average of more than 150 tornados occur every year (14); the width of the path of most tornados is only 15 to 100 yd., occasionally a mile, and the length is 10 to 15 miles (15). In the heart of the tornado region, extending from northeastern Oklahoma to northern Iowa, the total number of tornados per 50-mile square during 30 years (1920–1949) was somewhat greater than 15. Thus the chances are only about 1/5,000 that a tornado will strike any one square mile, even in this area, in any one year.[3] This probability is so slight, and the problem of withstanding the full fury of a tornado so great, that such winds need not be considered in designing small, movable structures.

The strongest winds, other than those of tornados, are caused by tropical cyclones: hurricanes and typhoons. These storms form in general during summer and fall near the equator, and move northwest and eventually northeast (in the northern hemisphere), although many deviations from this most common path have occurred. Some places, notably islands in the Caribbean and in the western Pacific, often experience two or even more hurricanes per year. Other places may be visited by hurricanes only once in 20 or 50 or 100 years. In either case, hurricane winds are part of the over-all pattern of the weather, as revealed by climatic records over a sufficient period of years. Consequently, the likelihood of hurricane winds at any place will be apparent from analysis of sufficiently long wind records.

Despite the fury of hurricane winds, average windiness is not high in hurricane regions; the highest average wind speeds are found much farther north, in the paths of the storms of middle latitudes. In the United States, the highest yearly average wind speeds (12) are more than 14 mph. along the coasts of Washington, Virginia, and New England;

[3] In his comprehensive "Tornadoes of the United States" (Norman, Univ. of Oklahoma Press, 1953, 194 pp.), Snowden D. Flora estimates (p. 34) "there is one chance in 1,203 that a given square mile in Iowa will be struck in any one year." This 56,280-square-mile state had 512 tornadoes between 1916 and 1949 (his Table II) for an annual average of one tornado per 3,737 square miles, more than twice the greatest frequency shown by Fawbush *et al* (14). However, "The average tornado path covers an area approximately three square miles," an estimate apparently based on an average length of 12 miles and an average width of ¼ mile. Averages in three different studies cited by Flora on p. 16 were 396, 440, and 438 yards, although earlier (15) he said "From 15 to 100 yards is common for their width."

in the hurricane area, Key West and Miami have average yearly speeds of about 10 mph.

Out of 189 Weather Bureau stations included in a manuscript tabulation, prepared by the Weather Bureau in 1950, 7 had average yearly wind speeds of 14 mph. or greater (Table I). For 53 of these places, and 5 others, another tabulation, "prepared in Climatic Information Section of C and HS Division, W.B., 4/23/51," gives maximum (5-min.) and extreme (fastest mile) speeds "for the entire period of record through 1950," and the percentages of hourly wind speeds (based on 10 years or less ending in 1938) in various groups. Of these 58, the 11 with maximum speeds of 70 mph. or greater are shown in Table I.

TABLE I.—*Records at Windy Places in the United States.*

A: Strongest Yearly Averages at Weather Bureau Stations

Anemometer Height, ft.	Station	Average Wind Speed, mph. Year	Windiest Month	
20 to 60	Block Island, R. I.	16.7	22.1	Jan.
48 to 172	Atlantic City, N. J.	15.0	16.9	Mar.
454	New York, N. Y.	14.8	17.1	Feb.
55 to 56	North Head, Wash.	14.7	16.6	Jan.-Dec.
96 to 280	Buffalo, N. Y.	14.5	17.6	Jan.
65 to 75	Great Falls, Mont.	14.2	18.8	Jan.
54 to 61	Tatoosh Island, Wash.	14.0	20.0	Jan.

B: Extremes and Frequencies of Strong Winds

Anemometer Height, ft.	Station	Percent of Hours 36 to 47	Over 47	Station Highest 5-min.	1-mile
168	Miami, Fla.	0.07	0.01	87	122
38	Mobile, Ala.	0.05	0.00	87	98
454	New York, N. Y.	1.94	0.06	81	99
61 to 100	Brownsville, Tex.	0.11	0.01	80	106
93 to 158	Wichita, Kans.	2.22	0.03	80	100
51	North Platte, Neb.	1.73	0.05	73	76
280	Buffalo, N. Y.	1.62	0.05	73	91
63	Boston, Mass.	0.49	0.01	73	87
92	Charleston, S. C.	0.47	0.00	72	81
114	Galveston, Tex.	0.52	0.07	71	91
49	Amarillo, Tex.	2.91	0.15	70	84

Height of anemometer appears, from this table, to have considerable effect on the average windiness, and even on the magnitude of the strongest wind: at both Buffalo and New York City the anemometers are unusually far above the ground.

These are not the strongest winds ever measured in the United States; that record (16) belongs to the observatory on the top of Mt. Washington, N. H., 6288 ft. above sea level. There, on 12 April, 1934, a wind speed reported as 231 mph., later corrected to 225 mph. after anemometer calibration, was registered twice. Because of the reduced air density, the force of this wind was equal to that of a 180-mph. wind

at sea level. This measurement came during an intense middle latitude storm; the strongest speed actually measured in a hurricane, at Blue Hill Observatory, Mass., in 1938, was 183 mph. (corrected), although much greater speeds are estimated for such storms from their effects.

For other parts of the world, detailed data on the frequency of strong winds are not as readily available. Conditions in Japan (17) and the British Isles (18) seem comparable to those along the coasts of the United States. In Alaska, Gambell on St. Lawrence Island, in Bering Sea, has an annual average wind speed of 17.8 mph., and during an 8-yr. period the extreme speed was 100 mph. (fastest mile), while St. Paul Island, where the average speed is 15.9 mph., has observed 114 mph.; in the interior, however, the strongest winds observed are less than 70 mph. (All values cited are as of 1950.)

In the Russian coastal Arctic (19), the strongest wind speed reported for any of the ten stations at which such records are kept is 129 mph. at Malye Karmakuly on Nova Zemlya. The fjords of Greenland are notoriously windy, but no records of very high winds have been made there. At "The Home of the Blizzard," a base occupied during two years on the Antarctic coast south of Australia (20), the combination of air drainage from the interior and strong storms to the north yielded an average speed over a 22-month period of 43 mph.; there a 12-hr. average of 89 mph., maximum 96 mph., was recorded in July, 1913, and a 24-hr. average of 81 mph., maximum over 100 mph., was measured the next month.

DATA

Adequate data for the determination of the strongest wind to be expected over most of the world are not readily available. Some information is available concerning frequencies of winds of various speeds over the oceans (21) and average wind speed data are available for many countries and the world as a whole (22). The strongest wind ever recorded is reported for a good many places, usually without information as to anemometer height or time interval. But records of the strongest wind in each year apparently have not been assembled, even in detailed tabulations which sometimes are prepared for individual places.

The areal extent and topographic diversity of the United States provide a fair sample of wind conditions of middle latitudes. Since these are among the windiest in the world, the search for detailed data was confined to this country. To insure uniformity of data, it was desirable to rely on stations at which anemometer height or exposure had not changed materially for many years.

Of more than 200 first-order Weather Bureau stations, 25 were selected, well-distributed geographically, at which anemometer height was less than 100 ft. and had not changed more than 10 ft. during the 37-yr. period, 1912 to 1948. The selection was made by tabulating

TABLE II.—*Strongest Maximum (5-min.) Wind Speed (mph.) During Each Year, 1912–1948, at 25 Places in the United States.*

Year	1912	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	Avg.	S.D.
Tatoosh Island, Wash.	68	51	65	61	68	54	57	70	71	84	59	69	62	60	61	68	68	56	66	62	65	63	71	59	59	69	68	61	78	71	74	64	62	66	59	61	66	64.8	6.47
North Head, Wash.	69	65	70	63	73	65	68	68	57	95	60	68	64	70	73	65	66	63	66	66	79	70	87	68	73	72	67	70	84	67	65	77	65	64	67	66	69	69.3	7.21
Eureka, Calif.	35	35	46	46	35	35	40	35	32	38	39	37	34	38	36	30	34	31	31	34	37	30	31	30	34	38	35	35	34	35	37	41	37	35	38	34	35	35.6	3.66
Baker, Ore.	27	30	39	28	28	30	38	30	28	28	30	27	25	30	40	37	29	26	29	27	28	35	26	32	29	28	30	38	28	27	34	28	25	30	28	30	33	30.1	3.92
Fresno, Calif.*	*30*	*30*	32	35	41	28	31	30	34	30	29	34	30	27	28	38	28	29	29	32	32	30	25	32	30	31	35	40	26	*35*	*31*	*30*	*34*	*32*	*35*	*31*	*34*	31.3	3.86
Winnemucca, Nev.	36	32	36	32	38	41	37	36	43	38	40	38	38	31	32	37	34	32	34	34	32	40	30	35	36	32	35	36	35	58	52	45	33	42	42	39	40	37.3	5.59
Yuma, Ariz.	32	32	29	32	32	37	32	34	30	33	33	34	29	35	30	30	30	38	29	34	34	35	30	35	32	29	34	34	29	29	31	29	30	33	37	34	41	32.4	2.90
Williston, N. D.	38	50	40	35	38	41	38	50	38	38	44	41	50	35	34	35	42	36	35	37	40	46	39	40	37	46	37	39	33	44	34	34	35	42	46	41	44	39.8	4.69
Sheridan, Wyo.	44	38	41	43	40	38	32	32	34	46	37	37	37	31	32	33	33	34	33	31	32	37	33	32	32	33	32	33	38	53	49	51	52	59	57	*66*	56	39.8	9.27
Valentine, Neb.	38	44	44	43	39	36	39	44	49	43	41	46	41	42	41	44	36	45	49	37	42	56	35	39	34	43	41	41	35	37	38	42	38	36	46	39	38	41.1	4.50
Oklahoma City, Okla.	56	41	44	57	48	43	57	46	43	37	40	38	46	35	36	38	34	38	38	29	32	32	34	38	30	34	32	33	33	31	33	26	34	28	31	37	33	37.7	7.61
Roswell, N. Mex.*	*37*	*50*	38	47	38	38	38	38	38	41	41	41	43	41	38	40	38	36	34	42	49	39	40	43	43	43	38	40	43	40	45	42	38	42	37	43	*51*	40.4	3.07
Corpus Christi, Tex.	47	41	41	40	90	38	50	95	41	51	43	39	44	38	37	39	37	36	43	35	47	49	47	39	49	42	50	38	43	37	61	54	45	56	43	51	39	46.3	12.6
Duluth, Minn.	54	49	49	46	50	45	51	45	49	54	53	54	50	45	54	54	57	52	47	39	49	51	59	51	49	53	54	50	52	68	55	50	54	49	61	49	49	51.4	4.94
Peoria, Ill.*	30	38	28	30	30	32	41	31	35	31	28	27	38	32	29	32	29	32	28	26	30	28	29	28	28	29	27	25	29	25	26	55	*46*	*42*	*41*	*54*	*48*	30.8	5.66
Cairo, Ill.	35	38	33	35	40	38	45	46	42	47	38	38	47	43	41	47	37	45	37	36	35	40	35	38	40	51	34	39	43	34	42	37	34	40	43	43	45	40.0	4.49
Birmingham, Ala.*	34	32	32	32	35	30	41	32	31	38	35	36	30	31	32	32	33	31	37	31	38	40	34	42	40	38	36	35	36	30	34	41	*41*	*47*	*45*	*43*	*40*	34.7	3.54
Alpena, Mich.	38	43	41	39	41	38	43	47	37	46	43	40	44	38	43	41	38	45	42	42	47	41	37	43	38	43	38	42	47	37	44	38	47	42	45	50	42	41.9	3.35
Canton, N. Y.	51	53	50	44	46	47	49	47	46	54	43	49	43	62	39	39	47	48	36	38	39	39	38	39	44	35	38	39	35	40	38	42	32	34	39	34	35	42.5	5.54
Burlington, Vt.	40	47	43	40	41	50	44	47	49	49	44	53	40	46	47	43	50	43	43	40	42	41	42	43	43	44	47	38	43	38	41	41	40	42	42	43	46	43.6	3.50
Eastport, Me.	53	41	54	49	60	54	52	56	48	39	57	46	46	51	38	50	45	50	48	52	42	46	51	48	46	46	45	47	46	49	46	42	51	55	44	52	48	48.5	4.87
Block Island, R. I.	60	54	65	66	56	59	54	54	56	56	56	47	60	56	56	59	54	52	54	51	59	60	57	62	58	47	82	56	50	52	57	70	82	63	57	67	57	58.4	7.47
Richmond, Va.	46	48	41	43	37	47	47	36	34	32	37	36	37	38	41	37	42	38	45	37	38	46	39	34	38	34	38	33	32	35	44	46	40	34	32	41	38	38.9	4.64
Charleston, S. C.	52	49	46	43	50	37	38	41	32	35	43	35	38	38	43	40	55	36	40	35	40	51	53	47	40	34	43	37	66	33	44	33	60	57	43	45	34	42.8	8.09
Key West, Fla.	32	40	39	44	41	40	40	84	40	38	41	40	51	41	49	44	37	61	34	46	40	43	32	46	38	43	33	33	42	40	35	40	56	40	35	54	73	43.4	10.6

* Italic figures not used in computing Average and Standard Deviation because of changes in anemometer heights.

the heights as given each month in the *Monthly Weather Review*, and verifying these heights for the chosen stations from the original records. From these records, in the National Archives and the Weather Bureau's central office, the monthly "extreme" (5-min.) winds were extracted, and then the annual extremes (Table II). (A few months after this tabulation was completed, the work of selection would have been much easier: the 1950 *Local Climatological Summary* for each Weather Bureau station carried a history of the station with details of exposure. This long overdue explanation of the climatic statistics, carried in even better form in the 1951 summaries, facilitates judicious selection of data and their detailed analysis.)

The requirements imposed as to anemometer height and period of record sharply restricted the choice of stations for tabulation and analysis. Many cities with reported high wind speeds (such as Chicago, Buffalo, New York City, and Atlantic City) were ignored because anemometers were much more than 100 ft. above the ground. Others which would have been desirable for better geographic coverage (such as Brownsville, Tex., Hatteras, N. C., and Los Angeles, Calif.) did not have observations at heights below 100 ft. for all or most of the years selected. At still others, the anemometer height, while below 100 ft. during the entire period, had varied more than 10 ft.

The "maximum" (5-min.) winds given in the original records prior to 1932 had to be corrected according to official Weather Bureau instructions (5). Up to 31 December 1927, all recorded wind speeds were the uncorrected readings of 4-cup Robinson anemometers. From 1928 through 1931, all speeds from the older 4-cup anemometers were corrected to agree with the readings of the 3-cup instruments, then being introduced, readings from which were not corrected to true speeds. From 1 January 1932 onward all readings, whether from 3-cup or 4-cup anemometers, were already corrected to true speed in the original records.

ANALYSIS

From the means and standard deviations of the strongest "maximum" (5-min.) winds in each of 37 years at the 25 selected places, the strongest such wind likely in any given period was determined from the theory of extreme values, as discussed above. The resulting values are shown in Fig. 1, from which the strongest 5-min. wind likely to occur at each station can be determined for any given "return period."

For most of the 25 stations, the strongest maximum wind speed increases with time at about the same rate, as shown by the slopes of the lines (which depend on the standard deviations). But the rate of increase with time is much sharper at a few places, such as Corpus Christi, Key West, Oklahoma City, and Miami. Here strongest winds of most years are relatively light, but very strong winds occur occasionally.

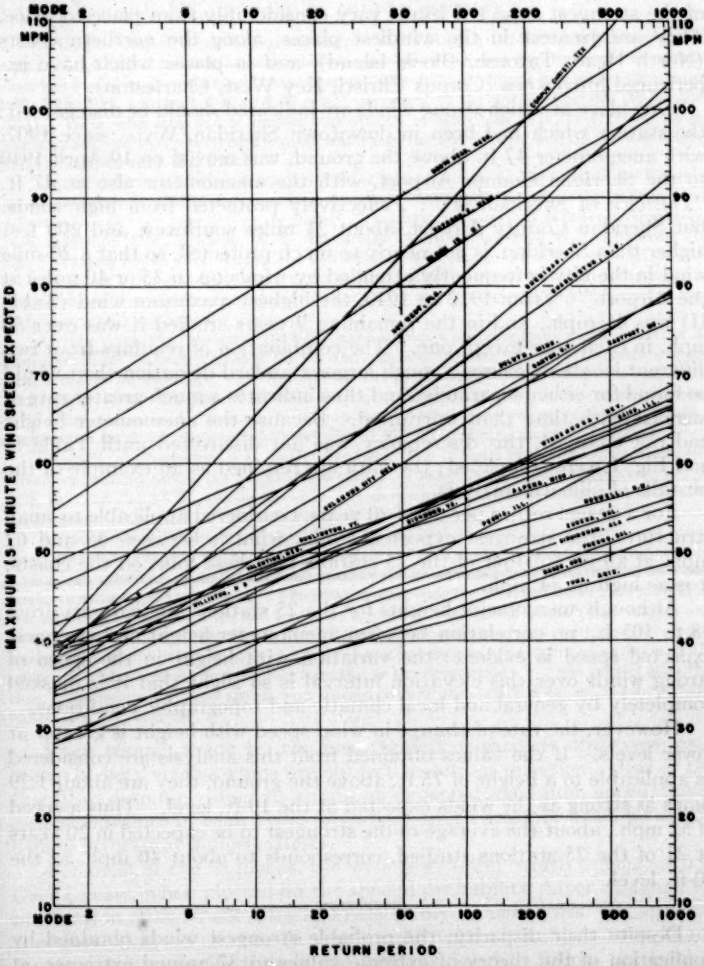

FIG. 1. Strongest 5-min. wind expected in 2 to 1000 years at 25 places in the United States.

Although the rates of increase are similar, the actual magnitudes of the strongest expected winds vary considerably from place to place. They are greatest in the windiest places, along the northern coasts (North Head, Tatoosh, Block Island), and in places which have experienced hurricanes (Corpus Christi, Key West, Charleston).

One place at which strong winds are indicated should be disregarded: the station which had been in downtown Sheridan, Wyo., since 1907, with anemometer 47 ft. above the ground, was moved on 19 April 1940 to the Sheridan County Airport, with the anemometer also at 47 ft. "The city of Sheridan is . . . effectively protected from high winds, but Sheridan County Airport, about 2½ miles southwest and 200 feet higher than Sheridan, is not nearly so much protected, so that a 20-mile wind in the city is frequently attended by winds up to 35 or 40 miles at the Airport." From 1912 to 1940, the highest maximum wind (Table II) was 41 mph., and in the remaining 9 years studied it was over 50 mph. in each year except one. The combination of readings from two different locations causes a much larger standard deviation than would be found for either separately, and thus indicates a much greater rate of increase with time than warranted. Because the anemometer height had not changed, this discrepancy was not discovered until Table II and Fig. 1 were completed; the data are retained as an example of the pit-falls of climatic analysis.

For a design return period of 20 years, considered applicable to small structures, the strongest expected 5-min. wind is between 38 and 62 mph. at all except four of the 25 stations; at these four, on the coasts, it is as high as 84 mph.

Although anemometer heights for the 25 stations studied vary from 38 to 105 ft., no correlation between anemometer height and strongest expected speed is evident: the variation with height in the speed of strong winds over this elevation interval is so slight that it is masked completely by general and local climatic and topographic conditions.

However, the rate of change in wind speed with height is greater at lower levels. If the values obtained from this analysis are considered as applicable to a height of 75 ft. above the ground, they are about 1.29 times as strong as the winds expected at the 10-ft. level. Thus a speed of 52 mph., about the average of the strongest to be expected in 20 years at 21 of the 25 stations studied, corresponds to about 40 mph. at the 10-ft. level.

DISCUSSION

Despite their disparity, the probable strongest winds obtained by application of the theory of extreme values to 37 annual extremes, at each of 25 stations, show much more homogeneity than the "strongest of record" which heretofore has been the only available indication of the likelihood of very strong winds. In many cases, the "strongest of

record," the value often cited in various summaries and publications, is extremely unreliable, and may be only an estimate.

At Corpus Christi, Tex., during a hurricane on 18 August 1916, "the wind instrument support was wrecked, most of the office windows were blown out, and the triple register mechanism was buried in glass splinters"; the observer "estimated maximum velocities of 90 miles at 6:50, 7:18, 8:15, and from 8:40 to 8:50 p.m.," according to the station's records (WB Form 1014). Three years later during another hurricane on 14 September 1919 "at 1:15 p.m. flying debris struck and partly severed the cable leading to the anemometer and no velocity record could be secured after that time."

A quarter century later, on 5 January 1946, a letter from the Acting Chief of the Weather Bureau announced: "After agreement of all offices concerned, the estimates of true wind velocities in miles per hour at Corpus Christi, Texas have been revised as follows: August 18, 1916, maximum 90 E, Extreme 100 E. September 14, 1919, maximum 95 NE, Extreme 110 NE." Various offices were "authorized and instructed to change records in accordance with revised values." Apparently it was estimated that, had the anemometer continued to function in those cases, it would have registered 119 and 125 mph., respectively, although nothing over 90 (uncorrected) was actually observed.

At Key West, Fla., the same 1919 hurricane similarly prevented any measurement of its strongest wind. "The hurricane of the 9th and 10th was the most violent in the history of the local Weather Bureau office. . . . As early as 7:01 p.m. of the 9th and before the loss of the anemometer, there were gusts of 92 miles per hour. Winds that could be classed as dangerous blew without cessation for 16 hours." The strongest 5-min. speed was estimated at 110 mph.; corrected to 84, this is the strongest maximum at Key West during the period studied.

Similarly, at Charleston, S. C., in October 1944, "For 16 hours 11 minutes the anemometer record was missing during the height of the storm. The estimated maximum velocity was 60 miles per hour about 7:15 a.m. on the 19th." This is Charleston's second highest speed during the 37 years.

At North Head, Wash., in January, 1921, "On the 29th at about 3:23 p.m. the most severe storm ever experienced in the history of this section of the country, broke. The wind reached a very high velocity. A maximum wind velocity of 150 miles per hour is thought to be a conservative estimate of the velocity. The wireless mast near the Weather Bureau office building was blown down and as it fell the southeast guy wires destroyed the instrument shelter and anemometer and storm warning tower. Before the anemometer was destroyed the record showed a maximum wind velocity of 126 miles and an extreme velocity for one minute of 150 miles. A higher velocity was reached after this as the destruction . . . was greater after this time." Subsequently, these speeds were crossed out and the corrected values, 113 for 150 and 95 for 126, were entered.

Even though made by the best-trained of weather observers, estimates of very strong winds are subject to serious question. Use of the theory of extreme values to obtain an expected maximum speed, based on the extremes of each year, provides a much sounder basis for establishing structural design criteria.

For most of the 25 places, the strongest 5-min. winds during each of the 37 years, when plotted on the special probability paper designed for application of the theory, formed reasonably straight lines. It appears, therefore, that occurrence of very strong winds is subject to so many independent variables that it can be considered to follow the laws of chance—as was assumed in the theoretical development.

However, if there is any periodicity to storminess, some of the analysis may be in error. For example, if hurricanes reach New Eng-

land at regular intervals of 20 to 25 years, the occurrence of very strong winds at Block Island cannot be due to chance, and should not follow the theory of extreme values.

All of the wind data discussed here do seem to follow the theory, and no proof of any periodicity in hurricanes, strong storms, or general windiness has yet been adduced. Thus it seems proper to consider strong winds as random variables, to analyze them according to the theories of statistics and probability, and to apply the results to problems of climatic estimation and engineering design.

CONCLUSION

Since coastal locations in northern middle latitudes, as well as hurricane areas, are much more likely to experience winds over 60 mph. during a 20-yr. period than are places over most of the interior, areas of *average windiness* may be distinguished from those of *extreme windiness*. Small, portable structures can be designed to meet the strongest wind likely in 20 years in areas of average windiness, and still be satisfactory for use in areas of extreme windiness if they are equipped with supplemental means of withstanding the greater winds.

Thus such structures, with expected lifetimes of 2 years with only a 10 per cent risk of failure due to strong winds in less than this time,

TABLE III.—*Design Wind Speeds Recommended for Structures of Various Life Expectancies with 10 per cent Calculated Risks, and Stronger Speeds for Which Auxiliary Equipment Should be Provided.*

Structure	Life Desired, yr.	Built-in		Auxiliary	
		5-min.	Gusts	5-min.	Gusts
Portable	2	40	60	60	90
Temporary	5	50	75	65	100
Semi-permanent	10	60	90	70	105

should be designed (as shown above) for 5-min. winds of no greater than 40 mph., and for gusts which are 50 per cent greater, or 60 mph. In addition, such structures should be capable, through the use of additional tie-down ropes, stiffening members, etc., of withstanding the higher winds of extreme windy places, such as sea-coasts and mountain tops; if the strongest wind expected in 20 years at such places is 84 mph. (North Head), the corresponding 10-ft. value is 60 mph., with gusts to 90 mph.

Although discussed entirely in terms of small, portable structures such as tents or vehicles with desired lifetimes of only two years, the approach and data of this report can be applied to larger structures, to those with longer desired lifetimes, or to those with different calculated risks of failure. For example, for a temporary structure which should last at least 5 years with only a 10 per cent risk of failure during that

interval, the design return period is $9.49 \times 5 = 47$ years. For this period, the strongest wind expected, in areas of average windiness, is (Fig. 1) between 40 and 65 mph., 50 to 100 ft. above the ground, and thus about 50 mph. at the height of the structure.

Similarly, for a semi-permanent structure intended to last at least 10 years with not more than a 10 per cent risk of failure, the design return period is 95 years, for which the expected winds (except on coasts) are between 42 and 73 mph.

These values, summarized in Table III, are admittedly crude estimates. They involve arbitrary assumptions about the expected lifetime and calculated risk, the corrections for elevation are inexact, and the variation in expected speeds from station to station in the relatively small sample makes crude generalization necessary. Nevertheless, the results appear to be more rational and logical than any criteria heretofore proposed for the design of structures to withstand strong winds.

Acknowledgments

Compilation of the data of Table II including corrections and computations, and plotting of Fig. 1, was done largely by Mrs. Vera Grove, statistician, assisted by Owen S. Parmele, statistical clerk, who also compiled Table I. The discussion of the world distribution of windiness is adapted from a report written originally by Norman Sissenwine, meteorologist, whose advice and discussion were extremely helpful in the conduct of this study and the preparation of this article. All research reported here was done early in 1951, while the author was Chief Climatologist in the Environmental Protection Section (now Branch), Research and Development Branch (now Division), Office of The Quartermaster General. It is published with the approval, but not necessarily the endorsement, of the Department of the Army.

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INTRODUCTION TO MONOGRAPH ON EXHAUST TURBOCHARGING

BY

RUPEN EKSERGIAN [1]

In 1952, The Franklin Institute awarded the Henderson Medal to Dr. Alfred J. Büchi, "In view of his contributions in augmenting the capacity and performance of the four-cycle Diesel Engine through his supercharging system in all classes of service, but particularly in the railway field."

The "Büchi system" for supercharging Diesel engines has had an extended application in the stationary marine and locomotive fields. In fact, it might be said that most modern Diesel engines would contain the Büchi system, or some modification of it, particularly in the four-cycle class. In the locomotive theater alone, in this country, the application amounts to practically seven million horsepower and for other classes throughout the world, to over fifteen million horsepower.

The development of the exhaust gas turbo supercharger is of particular interest, not only for its specific effect in augmenting the power of internal combustion engines, but also in its influence in the parallel field of the gas turbine power plant. For these reasons, it was suggested that Dr. Büchi submit a paper for the JOURNAL, on the research phase and the development history of the turbo supercharger.

In order to cover a comprehensive survey of the research and development of this work, and also to include a discussion of some future potentialities, Dr. Büchi has written a monograph, published separately under the auspices of the JOURNAL and titled "Exhaust Turbocharging of Internal Combustion Engines—Its Origin, Evolution, Present State of Development and Future Potentialities."[2]

A few preliminary remarks on Büchi's developments seem appropriate to note. In 1905 Dr. Büchi conceived a rotary compressor for compressing the charging air driven by a turbine using the exhaust gases of the engine. In 1911, at Sulzer Brothers in Winterthur, Switzerland, an experimental plant was erected by Dr. Büchi, consisting of an air compressor, Diesel engine and exhaust gas turbine. The equipment was separated. In this way Dr. Büchi knew exactly the power of each component and from the results was able to calculate the various combinations of supercharging with an exhaust-gas turbo-driven blower. The results of this pioneer research were widely published.

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[2] Copies of the monograph may be ordered through the JOURNAL office.

In the early attempts at supercharging, it was assumed that the best result would be obtained by maintaining a steady pressure at the nozzle entrance to the turbine. Exhaust manifolds were designed with exceptionally large capacity so that the pressure pulsations could be reduced. Under these conditions, the air pressure delivered by the blower was approximately equal to the exhaust pressure to the turbine; consequently, effective scavenging was poor and conditions were soon reached where the exhaust temperature attained the maximum allowable values for the turbine blades. In the Büchi system the exhaust pipe between the engine and turbine was specifically designed to induce pressure fluctuations in the pipe. At the exhaust opening of the engine, the pressure rose to a high differential value, this being partly absorbed by throttling the exhaust gases through the exhaust pipe. The exhaust pipe can be regarded as an acoustic bottle where the gases in the cylinder represent the elastic medium and the exhaust pipe represents the inertia element of the flow. By timing this system, consistent with the period of the engine rotation, a suction effect is obtained in the cylinder after the gas is accelerated along the pipe during the exhaust period. This results in a lowered pressure at the beginning of scavenging, an increased volumetric efficiency for the intake air, and improved cooling of the cylinder. The inertia of the exhaust gases, in turn, maintains a more uniform torque at the turbine, thereby augmenting the compression during the initial air intake to the cylinder. The Büchi system requires special combinations of piping to the cylinders in order to carry out this operation without interference of the exhaust gases. On the basis of this system, consisting of special combinations of piping to multi-cylinder engines, along with a vastly improved design of compressor and turbine, resulting in high efficiencies, the Büchi system for supercharging four-cycle Diesel engines has augmented the power from 30 to 50 per cent, and, in special designs, over 100 per cent.

Dr. Büchi, in the "Conclusions" of his monograph, gives future trends in power units. Relative to supercharged engines, he points out the opportunities in design in the high and very high turbocharging pressure ratios, and also the opportunities in extending the field of supercharging to two-stroke engines, replacing scavenging pumps of the Roots type with rotary blowers.

Most interesting, however, is his forecast of a new type of power-gas-generator gas turbine, in which a four-cycle Diesel engine is employed solely as a power-gas generator to drive scavenging reciprocating compressors. The high pressure exhaust gases of the reciprocating unit are utilized in turn for the power-gas turbine. A preliminary design of a 6000-hp. internal combustion power-gas-generator turbine is included. This power-gas generator is applied to a design for a 6000-hp. gas-turbine locomotive.

SOLUTION OF ALGEBRAIC EQUATIONS

BY

LELAND E. ALDRICH [1]

This paper describes a method, believed to be original, for the rapid solution of algebraic equations. The method is especially rapid when a calculating machine is used. The possibilities of adaptation of the method to the solution of equations other than algebraic polynomial equations with integral powers, have not as yet been explored by the author.

We may write the general nth order equation

$$A_0x^n + A_1x^{n-1} + A_2x^{n-2} + \cdots + A_{n-1}x + A_n = 0 \qquad (A)$$

in the form

$$x^n = -A_0^{-1}(A_1x^{n-1} + A_2x^{n-2} + \cdots + A_{n-1}x + A_n) = V_n, \quad (a)$$

where V_n is the right member of (a), containing powers of x no higher than the $(n-1)$th.

Multiplying (a) by x, and writing V_n for x^n, we obtain

$$x^{n+1} = -A_0^{-1}(A_1V_n + A_2x^{n-1} + \cdots + A_{n-1}x^2 + A_nx) = V_{n+1}, \quad (b)$$

where V_{n+1} is the right member of (b), containing powers of x no higher than the $(n-1)$th.

Multiplying (a) by x^2 and writing V_n for x^n and V_{n+1} for x^{n+1}, we obtain

$$\begin{aligned} x^{n+2} &= -A_0^{-1}(A_1V_{n+1} + A_2V_n + A_3x^{n-1} + \cdots + A_{n-1}x^3 + A_nx^2) \\ &= V_{n+2} \end{aligned} \qquad (c)$$

$$\begin{aligned} x^{n+m} &= -A_0^{-1}(A_1V_{n+m-1} + A_2V_{n+m-2} + \cdots + A_{n-1}V_{m+1} + A_nV_m) \\ &= V_{n+m}. \end{aligned} \qquad (m \geqq n) \quad (d)$$

It will be noted that the right member of (d) contains powers of x no higher than the $(n-1)$th.

If we form a sequence $V_n, V_{n+1}, \cdots, V_{n+m}, \cdots$, it is seen that in the successive terms the coefficients are adding, multiplying and acquir-

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ing large exponents, while at no time are the exponents of x higher than the value $(n-1)$. As the sequence progresses, then, the value of x, in the right member, has a diminishing influence in determining the value of the terms.

In fact, if a ratio V_p/V_{p-1} is made, with p large, very little difference is found in the value of the ratio as x, in the right member, is changed (but not in general set equal to any root). If x be assigned a value which is not a root of (A), then the relations (a)–(d) cease to be correct—but the above ratio is not greatly affected.

In the general algebraic equation (A), let

$$x = R_1, R_2, \cdots, R_n,$$

where $R_1 \geqq R_2 \geqq \cdots \geqq R_n$, numerically. Then generally

$$R_1 = \lim_{p \to \infty} \left| \frac{U_p}{U_{p-1}} \right|, \tag{1}$$

where $U_0, U_1, \cdots, U_{n-1}$ can be assigned any value or values for which

$$U_p/U_{p-1} \neq R_2, R_3, \cdots, R_n. \qquad (p \leqq n-1)$$

(Generally $U_0, U_1, \cdots, U_{n-1}$ can be assigned the value unity.)

$$\begin{aligned} U_n &= -A_0^{-1}(A_1U_{n-1} + A_2U_{n-2} + \cdots + A_{n-1}U_1 + A_nU_0) \\ U_{n+1} &= -A_0^{-1}(A_1U_n + A_2U_{n-1} + \cdots + A_{n-1}U_2 + A_nU_1) \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ U_p &= -A_0^{-1}(A_1U_{p-1} + A_2U_{p-2} + \cdots + A_{n-1}U_{p-(n-1)} + A_nU_{p-n}). \end{aligned}$$

Since the coefficients of the higher powers of x wield the greatest influence in determining the values of the successive terms of the U_p sequence $(U_n, U_{n+1}, \cdots, U_p)$, the limit approached by the U_p/U_{p-1} sequence will be R_1, the root having the greatest numerical value.

The above ratio, whether consistent or not throughout the range of $p \leqq n-1$, can be thought of as a trial root which converges to R_1 automatically as p is given larger and larger values.

The larger the numerical value of any root, other than R_1, the more influence it has in lessening the *rate* of convergence of U_p/U_{p-1}. If the roots are of the same sign as R_1, then U_p/U_{p-1} converges to R_1 according to a curve whose *slope* is monotone. If a root R_a is of opposite sign from R_1, the result is to make U_p/U_{p-1} vary along an undulating or oscillating curve. The disturbances become more pronounced as R_a is given larger numerical values, until in the special case of R_a being equal

to R_1, then the U_p/U_{p-1} sequence oscillates over a range which approaches a constant value. Under this condition, the limit in (1) does not exist. If this condition nearly exists, the limit in (1) is approached too slowly to be useful. This is an ideal condition for the following two methods.

In any case, where R_1 is real or imaginary, or, if complex, has no conjugates among the roots,

$$R_1 = \lim_{p\to\infty} \left| \pm \left(\frac{U_{p+y}}{U_p} \right)^{1/y} \right|, \tag{2}$$

where y is the number of terms in the U_p sequence, between the successive greatest, or least, values of the ratios U_p/U_{p-1}. (In my experience, y generally equals 1 or 2.)

When the successive ratios U_p/U_{p-1} oscillate over a range approaching a constant value, this range is generally disposed symmetrically about R_1: then generally

$$R_1 = \lim_{p\to\infty} |0.5(U_p/U_{p-1} + U_{p+z}/U_{p+z-1})|, \tag{3}$$

where z is the number of terms in the U_p sequence, between the successive greatest *and* least values of the ratios U_p/U_{p-1}. Exceptions to (3), in addition to those of (2), may occur when the maximum (or minimum) values of U_p/U_{p-1} remain constant throughout the range of p. Of course, an imaginary root, with a conjugant, could not be found by method (3).

Familiarity with the method makes it possible to estimate the accuracy attained at any stage by (2) or (3) without their solution.

If a solution is not arrived at rapidly, but an approximate root is seen, it may be useful to start a new solution, letting $U_1/U_0, \cdots, U_{n-1}/U_{n-2}$ have a convenient (but not necessarily a consistent) value near the approximate root found in the first attempt. That is, if, say, it is seen a root lies between 2 and 3, but closer to 2, we may let $U_0, U_1, \cdots, U_{n-1}$ have the values 1, 2, 5, 12, etc., respectively.

If all the influential roots are of the same sign as R_1, the convergence of U_p/U_{p-1} can be too slow for (1) to be practical. In this case an oscillating sequence can generally be had from a new equation obtained by reducing (or increasing) the roots of (A) sufficiently, and then solving by the appropriate method. (This may give, and is indeed a method for the solution of, a root other than R_1.) If, on the other hand, (A) be written

$$A_n s^n + A_{n-1}s^{n-1} + \cdots + A_1 s + A_0 = 0$$

where $s = x^{-1}$ for every root, we have $R_n^{-1} \geqq R_{n-1}^{-1} \geqq \cdots \geqq R_1^{-1}$,

numerically. Then generally

$$R_n = \lim_{p \to \infty} |U'_{p-1}/U_p'|,$$

where

$$U_p' = -A_n^{-1}(A_{n-1}U'_{p-1} + A_{n-2}U'_{p-2} + \cdots + A_1U'_{p-(n-1)} + A_0U'_{p-n}).$$

When method (2), using a value y, oscillates over a wide range or the same range as method (1), then perform method (2) using a value $2y$.

An apparently useless U_p/U_{p-1} sequence is obtained when R_1 is complex and has a conjugate among the roots, where the real component s not zero.

If R_1 (or R_n) is complex, and has a conjugate among the roots, the value of R_1 (or R_n) can be found by writing a new equation whose roots are reduced by i and solving for $R_1 - i$, $R_n - i$.

If a random convergence by any method is noted, a complex root near the numerical value of R_1 is indicated.

EXAMPLES

The following examples are included to show some of the exceptions, and extreme cases, and to give an idea of the mechanics of the method.

$$A_w' = -A_0^{-1}A_{n-p}. \qquad (p < n)$$

U_n is found by multiplying the A_w' and U_p columns and adding; U_{n+1} is found by moving the A_w' column down one row and multiplying the columns and adding. Repeat the process for as many terms as are desired.

Solve for R_1 $\qquad x^3 - 2x^2 + 81x - 162 = 0 \qquad (x = i9, -i9, 2.)$

p	A_w'	U_p	Method 1	Method 2 *
0	162	1		
1	−81	1	1	
2	2	1	1	1
3		83	83	83
4		284	3.421686	284
5		−5993	−21.102112	−72.204819
6		−21544	3.5948606	−75.859154
7		488353	−26.677033	−81.487235
8		1750904	3.5853245	−81.271073
9		−39544913	−25.854261	−80.976082
10		−141799864	3.585792	−80.986841
		.	.	.
		.	.	.
				−81.0

* Square root not carried out.

Solve for R_1 $x^3 - 13x^2 + 40x - 36 = 0$ $(x = 9, 2, 2.)$

p	$A_{n'}$	U_p	Method 1
0	36	1	
1	−40	1	1
2	13	1	1
3		9	9
4		113	12.555555
5		1145	10.132743
6		10689	9.335371
7		96864	9.062026
8		872892	9.0115213
9		7857840	9.0020758
		.	.
		.	.
			9.0

Solve for R_1 $x^3 - 6x^2 + 12x - 8 = 0$ $(x = 2, 2, 2.)$

p	$A_{n'}$	U_p	Method 1
0	8	1	
1	−12	1	1
2	6	1	1
3		2	2
4		8	4
5		32	4
6		108	3.375
7		328	3.0370370
8		928	2.8299268
9		2498	2.6896551
10		6464	2.5897435
		.	.
		.	.
			2

Solve for R_1 $x^3 - 7x - 18 = 0$ $(x = 9, -2.)$

p	$A_{n'}$	U_p	Method 1
0	18	1	
1	7	1	1
2		25	25
3		193	7.72
4		1801	9.3316062
5		16081	8.9289283
6		144985	9.0159194
7		1304353	8.9964686
8		11740201	9.0007850
9		105659761	8.9998262
		.	.
		.	.
			9.0

Solve for R_1 $x^3 - 4x + 4 = 0$ $(x = 2, 2.)$

p	A_n'	U_p	Method 1
0	−4	1	
1	4	1	1
2		0	
3		−4	0
4		−16	4
5		−48	3
6		−128	2.6666666
7		−320	2.5
8		−768	2.4
9		−1792	2.3333333
10		−4116	2.2968750
11		−9296	2.2585034
12		−20720	2.228915
13		−45696	2.2054054
14		−99904	2.1852745
15		−216832	2.1704035
16		−467712	2.1570247
17		−1003520	2.1455938
18		−2143232	2.1357142
		.	.
		.	.
			2.0

Solve for R_1 $x^4 - 85x^2 + 324 = 0$ $(x = 9, 9, -9, -9.)$

p	A_n'	U_p	Method 1	Method 2 *
0	−324	1		
1	0	1	1	
2	85	1	1	1
3	0	1	1	1
4		−239	−239	−239
5		−239	1	−239
6		−20639	86.35564	86.35564
7		−20630	1	86.35564
8		−1675879	81.199622	81.199622
9		−1675879	1	81.199622
10		−135762679	81.009779	81.009779
			.	.
			.	.
			1	81
			81	81

* Square root not carried out.
Methods 1 and 3 will not solve this problem with the above trial root.

Solve for R_1 $\quad x^3 - 2x^2 - 9x + 18 = 0 \quad (x = 3, -3, 2.)$

p	A_w'	U_p	Method 1	Method 2 *
0	−18	1		
1	9	2	2	
2	2	5	2.5	5
3		10	2	5
4		29	2.9	5.8
5		58	2	5.8
6		197	3.3965517	6.7931034
7		394	2	6.7931034
8		1517	3.8502534	7.7005076
9		3034	2	7.7005076
10		12629	4.1624917	8.3249834
11		25258	2	8.3249834
12		109565	4.3381770	8.6756671
13		219130	2	8.6756671
14		969601	4.4247752	8.8495504
15		1939202	2	8.8495504
16		8660473	4.4659983	8.9319967
17		17320946	2	8.9319967
18		77680513	4.4847731	8.9699605
19		155361026	2	8.9699605
20		698059641	4.493145	8.9862906
		.	.	.
		.	.	.
				9
				9

* Square root not carried out.
Methods 1 and 3 will not solve this problem with the above trial root.

Solve for R_1 $\quad x^3 - 9x^2 - 4x + 36 = 0 \quad (x = 9, 2, -2.)$

p	A_w'	U_p	Method 1
0	−36	1	
1	4	1	1
2	9	1	1
3		−23	−23
4		−237	10.304347
5		−2077	8.763713
6		−18817	9.0597014
7		−169119	8.9875644
8		−1522567	9.0029328
		.	.
		.	.

Solve for R_1 $x^4 - 20x^3 + 5x^2 - 2x + 1 = 0$ $(x = ?)$

p	$A_{w'}$	U_p	Method 1
0	−1	1	
1	2	1	1
2	−5	1	1
3	20	1	1
4		16	16
5		316	19.75··
6		6241	19.75··
7		123271	19.7518··
8		2434831	19.751855··
9		48092431	19.75185546··
10		949914766	19.75185587··
		.	.
		.	.

Solve for R_1 $x^4 - 8x^3 + 16 = 0$ $(x = 2, 2, -2, -2.)$

p	$A_{w'}$	U_p	Method 1	Method 2 *	Method 3
0	−16	1			
1	0	1	1		
2	8	1	1	1	
3	0	1	1	1	
4		−8	−8	−8	
5		−8	1	−8	
6		−80	10	10	
7		−80	1	10	
8		−512	6.4	6.4	
9		−512	1	6.4	
10		−2816	5.5	5.5	
11		−2816	1	5.5	
12		−14336	5.0909090	5.0909090	
13		−14336	1	5.0909090	
14		−69632	4.8571428	4.8571423	
15		−69632	1	4.8571423	2.9285714
16		−327680	4.7058823	4.7058823	2.85294125
.			.	.	.
.			.	.	.
.			.	.	.
			1		
			4.0	4.0	2.5

* Square root not carried out.
Methods 1 and 3 will not solve this problem with the above trial root.

Solve for R_1 $\quad x^4 - 8x^2 + 16 = 0 \quad$ $(x = 2, 2, -2, -2.)$

p	A_w'	U_p	Method 1	Method 2	Method 3, $z = 1$
0	−16	1			
1	0	2	2.0		
2	8	1	0.5	1	1.125
3	0	1	1.0	.	.
4		−8	−8.0	.	.
5		−24	3.0	.	.
6		−80	3.3333333	.	.
7		−208	2.60		.
8		−512	2.4615384		
9		−1280	2.4806201		
10		−2816	2.20		
11		−6912	2.4545454		
12		−14336	2.0740740		
13		−34816	2.42857		
14		−69632	2.0		
15		−167936	2.4117647	$(4.8235\cdots)^{\frac{1}{4}}$	2.20588235
16		−327680	1.9512195	$(4.7058\cdots)^{\frac{1}{4}}$	2.1814921
.		.	.	.	.
.		.	.	.	.
				$(4.0)^{\frac{1}{4}}$	2.0

Method 1 cannot solve this problem with the above trial root.

Solve for R_1 $\quad x^3 - 3x^2 + 9x - 27 = 0 \quad$ $(x = 3, i3, -i3.)$

p	A_w'	U_p	Method 1	Method 2 ($y = 4$)	Method 3
0	27	1			
1	−9	1	1		
2	3	1	1		
3		21	21	$21^{\frac{1}{3}}$	no solution
4		81	4−	$81^{\frac{1}{3}}$	
5		81	1	$81^{\frac{1}{3}}$	
6		81	1	3	
7		(81)(21)	21	3	
8		(81)(81)	4−	3	
9		(81)(81)	1	3	
.		.	.	.	
.		.	.	.	

Method 2 is the only method that will solve this problem for "1" as a trial root.

Solve for R_1 $x^2 - 11x + 18 = 0$ $(x = 9, 2.)$

p	A_p'	U_p	Method 1	Method 2	Method 3
0	−18	1			
1	11	1	1		
2		−7	−7	same as (1)	same as (1)
3		−95	13.571428		
4		−915	9.6736842		
5		−8399	9.1392818		
6		−75847	9.0304798		
7		−683135	9.0067504		
8		−6149239	9.0014989		
		.	.		
		.	.		
		.	.		
			9.0		

Solve for R_1 $x^2 - 18x + 81 = 0$ $(x = 9, 9.)$

p	A_p'	U_p	Method 1	Method 2	Method 3
0	−81	1			
1	18	1	1	same as (1)	same as (1)
2		−63	−63		
3		−1215	19.285714		
4		−16767	13.8		
5		−203391	12.130434		
6		−2302911	11.322580		
		.	.		
		.	.		

p	A_p'	U_p	Method 1
		Trial root = 10	
0	−81	−1	
1	18	−10	10
2		−99	9.9
3		−972	9.8181818
4		−9477	9.75
		.	.
		.	.
		Trial root = 9.5	
0	−81	−10	
1	18	−95	9.5
2		−900	9.4736842
3		−8505	9.45
		.	.
		.	.
		Trial root = 9.4	
0	−81	−10	
1	18	−94	9.4
2		−886	9.3829787
		.	.
		.	.

Trial root = 9

0	−81	−1	
1	18	−9	9
2		−81	9
3		−729	9
4		−6561	9

Solve for R_1 $x^4 - 5x^3 + 3x^2 + 2x + 1 =$ $(x = ?)$

p	A_p'	U_p	Method 1 *
0	−1	1	
1	−2	1	1
2	−3	1	1
3	5	1	1
4		−1	−1
5		−11	11
6		−55	5
7		−241	4.3·····
8		−1017	4.2·····
9		−4241	4.1·····
10		−17617	4.15·····
11		−73087	4.148·····
12		−303085	4.146·····
13		−1256689	4.1465·····
14		−5210399	4.1461·····
15		−21602671	4.1460·····
16		−89565673	4.14604····
17		−371342865	4.14604····
18		−1539601565	4.146037···
		.	.
		.	.

Repeat with trial root equal approximately four. (Not necessary for the solution.)

p	A_p'	U_p	Method 1 *
0	−1	0.25**	
1	−2	1	
2	−3	4	4
3	5	16	4
4		66	4.13····
5		273	4.136····
6		1131	4.1427····
7		4688	4.145····
8		19436	4.1456····
9		80576	4.14592····
10		334068	4.14599····
11		1385054	4.1460241····
12		5742479	4.1460325·····
		.	
		.	

* Decimal places carried only when they repeat in next row.
** Of minor importance and not used.
The root has to be between 4.146037··· and 4.1460325···.

Gas Industrial Truck with Electric Transmission.—The first gas-powered industrial truck with electric transmission, named the "Dynamotive," was shown for the first time at the Fifth National Materials Handling Exposition in Philadelphia. Developed by Automatic Transportation Company of Chicago, the Dynamotive, entirely new to the materials handling field, features radical changes both in design and appearance. It is styled by Col. Alexis de Sakhnoffsky, widely-known industrial and sports car stylist.

The gas-powered, electric driven truck offers to industry the traditional low maintenance costs, performance characteristics, and long life of straight electric trucks, plus the constant power service that can be derived from a gasoline engine.

Its electric, infinite step transmission has no mechanical connections from engine to drive unit, eliminating transmission gears, and the need for hydraulic torque converters or overdrive mechanisms.

Electric transmission provides fully controlled power and infinite acceleration range with minimum power loss, insuring maximum economy and efficiency. Since there is no mechanical connection between engine and wheels, transmission shock loads to engine are entirely eliminated, assuring maximum engine life.

John A. Baldinger, general manager of Automatic, pointed out advantages gained from the Dynamotive's modern design. Greater safety and driver comfort result from such styling innovations as greater vision from the driver's seat; a full-size bench-type seat; extra leg room; centralized controls; and grouping of all instruments on the steering post column. Rear contours have been shortened, reducing aisle projections and contributing to over-all operating efficiency as well as appearance.

An unusual safety feature is provided in interlocking the hydraulic service wheel brakes with emergency disc brakes in such a manner that instantaneous application of the emergency brakes is attained by the same pedal in case of hydraulic brake failure.

Ease of maintenance and exceptional accessibility of engine also result from design and styling factors.

All parts not requiring quick or frequent access are shielded, for greater cleanliness, and at the same time providing protection against damage. For servicing, the hood hinges forward, disclosing the entire engine compartment.

Greater stability is a direct result of modern design and styling. Architecturally correct, the truck is extremely low in chassis height, with heavier sections at the bottom, and it literally sets on its haunches.

Gauges on the cluster-type instrument panel measure amperage, temperature, oil pressure, and fuel level.

A new Automatic optional feature is a load indicator, showing weight of material on the truck's forks at any given time. This will prevent overloading past capacity, another safety factor.

Incorporated in the new Dynamotive are Automatic's many industry-proven features, including exclusive silicone insulation for electric components; heavy section rolled manganese alloy uprights; ball-bearing mounted carriage and upright rollers; and hydraulic safety fuses on the duo-lift models.

Capacities of the Dynamotive range from 4000 to 6000 lb. Heights of telescoping lifts are 124 in., with a standard 83-in. over-all height, for either mono-lift or duo-lift models.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS *

A SIMPLE MAGNETIZER

A magnetizer for permanent magnets that has recently been constructed at the National Bureau of Standards is unusually compact, portable, and low in cost. Devised by George M. Orr of the NBS electromechanical ordnance laboratories, the magnetizer requires only a few simple and relatively inexpensive parts and weighs only 21 lb. It normally operates from 110-volts a.c. drawing only about 30 watts yet giving peak magnetomotive forces as high as 20,000 ampere-turns.

Because of the complication, size, and expense of most magnetizing equipment, the "charging" (magnetizing) of permanent magnets has been largely confined to production lines and to a few well-equipped laboratories. Two methods are in general use at present. In one of these, a current pulse of the order of 50,000 amperes, and a duration of a few microseconds is passed through a single turn of heavy copper strap that circles the magnet. Equipment for this pulse method is relatively expensive, often bulky, and not always satisfactory. In another method, often used when 110-volt d-c. power is available, a coil of several thousand turns wound on a soft-iron yoke is connected across the line for a few seconds; the permanent magnet to be charged is placed between the pole pieces of the iron yoke. With this method, disconnection of the highly inductive load may present a problem, and flux density is limited by magnetic saturation of the iron yoke and by heating of the coil.

The Bureau's device is a form of "flash" magnetizer in which a large capacitor is quickly discharged through the magnetizing coil. Although flash magnetizing may not be fully effective for large magnets (the short duration of the magnetizing pulse does not always permit the magnetizing flux to reach full value below the surface of the magnet), it is often quite satisfactory for smaller ones.

In the newly constructed unit, a 6500-microfarad capacitor bank is charged to about 125 volts by selenium rectification of the a-c. line voltage. Energy stored in the capacitor is transferred to the magnetizing coil by a heavy-duty 24-volt 70-ampere motor-starting relay. The relay coil is actuated by a push switch. Since the relay gets its operating power from the capacitor bank, it opens shortly before the capacitor voltage has fallen to zero. Because the relay contacts thus open at a time when the current through them is low, high current-interrupting capability is not required.

* Communicated by the Director.

The unit was built at the Bureau at a total cost of less than $50, using mostly war surplus parts. Capacitors rated at 650 microfarads 80 volts d.c. were obtained for about $1.50 each; after a forming period they operated satisfactorily at 125 volts. Power consumption varies between 70 watts (capacitor discharged) and 10 watts (capacitor charged); at the normal rate of magnet charging—one pulse every 15 seconds—the average line power drain is no more than 30 watts. Because of this low power requirement, the unit could easily be designed to operate from batteries for portable use.

Several magnetizing coils have been constructed for the magnetizer, of designs that varied with the shape of the object to be magnetized. Although iron yokes are necessary for multipolar or radial magnetizing, simple layer-wound solenoids have been found quite satisfactory for general use. Optimum coils have from 150 to 200 turns, a d-c. resistance in the range of 0.3 to 1.0 ohm, and an inside diameter no larger than necessary to accommodate the magnet to be charged. In typical operation with such a coil, the peak current has an amplitude of the order of 150 amperes and a duration of roughly 2 milliseconds.

SENSITIVE CORROSION MEASUREMENTS WITH AN INTERFEROMETER

An interferometer procedure is being used at the National Bureau of Standards for studies of the corrosion resistance of such materials as optical glass, porcelain enamel, quartz and other natural and artificial silicates, and various metals. The method is believed to have value for comparing and predicting the chemical durability of various materials. Although interferometers have been widely used in science and industry for such problems as checking the accuracy of block gages, measuring expansion, and checking optical "flats," they have apparently been used very little in previous studies of corrosion resistance. With the highly sensitive interferometer method, corrosion to a depth of as little as 1 or 2 ten-millionths of an inch can be detected on optically flat specimens.

In the NBS technique, devised by Robert G. Pike and Donald Hubbard of the Bureau's mineral products laboratories, specimens are ground and polished to optical flatness and then immersed to half their depth in the desired corrosive solution. After the desired length of time they are withdrawn, rinsed and dried, and covered with an optically flat piece of quartz. Using a conventional interferometric viewing apparatus of the Pulfrich type, and with an unfiltered helium lamp for illumination, the displacement of the optical interference fringes at the level-of-solution line of the specimen is observed.

As seen by the observer looking into the eyepiece of the instrument, these interference fringes are vertical parallel lines. If the uniform flatness of the specimen under study has not been impaired by the cor-

rosive solution, these fringes are straight and continuous. However, if the previously-immersed part of the specimen surface has been sensibly attacked, each of the vertical fringes is shifted laterally at the point where it crosses the change-of-thickness line. If as sometimes happens the solution has caused swelling of the specimen, the lateral shift is in the opposite direction. A lateral shift equal to the space between two adjacent fringes corresponds to a dimensional change in the specimen amounting to one-half wavelength of light, or roughly 0.3 micron. (A micron is a millionth of a meter or about 40 millionths of an inch.) With careful use of the interferometer, changes in specimen thickness of as little as 0.003 micron can be detected.

Silicates studied by this procedure at NBS were quartz, fused silica, opal, obsidian, flint, and pitchstone. Porcelain enamels studied were acid-resistant, class A; "glass-lined" tank; and acid-resistant, class D. Metals were cold-rolled steel, aluminum, copper, brass, silver, and platinum. The corrosive agents ranged from concentrated sulfuric acid (H_2SO_4) to 5-per cent sodium hydroxide (NaOH) solution. Exposure times were as short as one minute and as long as several weeks. Temperature in most cases was held at 80° C.

A number of interesting and sometimes unexpected results were obtained. Swelling of the immersed surface, rather than attack, was found in several cases. For instance, crystalline quartz showed definite swelling after 2 weeks at 80° C. in an acid solution (pH 4.1). Opal—like quartz, a form of silica (SiO_2)—showed swelling of nearly 1 fringe of light at pH 2 and continued at a similar level to about pH 8; between pH 8 and pH 11, however, the swelling changed rapidly to an attack of $3\frac{1}{2}$ fringes. Although brass was attacked by strongly acid and strongly alkaline solutions, there was a slight indication of swelling in the more nearly neutral solutions. Such apparent swelling could perhaps be caused by the formation of a layer of insoluble salt having greater volume than the metal from which it was formed. Of the metals studied, only platinum showed no detectable dimensional change under the laboratory conditions. The three types of porcelain enamels studied varied widely in their chemical inertness as indicated by the test.

NOTE: For further details, see "An Interferometer Procedure Applied to the Study of the Chemical Durability of Silicates, Enamels, and Metals," by Robert G. Pike and Donald Hubbard, *J. Research NBS*, Vol. 50, p. 87 (Feb. 1953), NBS Research Paper 2394. See also, "Studies of the Chemical Durability of Glass by an Interferometer Method," by Donald Hubbard and Edgar H. Hamilton, *J. Research NBS*, Vol. 27, p. 143 (1941), NBS Research Paper 1409.

THE FRANKLIN INSTITUTE

ANNUAL REPORT OF THE BOARD OF MANAGERS FOR THE YEAR 1952

The Annual Report of the Board of Managers for the year 1952 is presented to the membership by the President on behalf of the Board.

OFFICERS AND BOARD OF MANAGERS

Richard T. Nalle retired as President after having served in that office for five years. S. Wyman Rolph was elected to succeed him at the annual Organization Meeting of the Board of Managers. Other officers elected for 1952 were: Executive Vice-President—Henry B. Allen; Vice-Presidents—Richard W. Lloyd, G. H. Clamer, James H. Robins, and Morton Gibbons-Neff; Secretary—Henry B. Allen; Treasurer—Hamilton V. Bail; Assistant Secretaries—Hamilton V. Bail and John Frazer; Assistant Treasurer—Cecil M. Waterbury.

On February 20th, the Board of Managers regretfully accepted the resignations of Edward Warwick, who had served as a member of the Board since December 1940, and of Morton M. Price, who had served as a member since November 1947. Mr. Price, who resigned because of ill health, died on September 11th. Also recorded with deep regret was the death on March 1st of Walton Forstall, who had served as a member since 1908.

On November 19th, R. G. Rincliffe and J. G. Richard Heckscher were elected to fill two of the vacancies thus created.

MEETINGS

Attendance averaged 288 at the seventeen stated meetings and meetings held jointly with various technical societies. Average attendance at the dinners preceding these meetings was 119. The joint meeting with the American Patent Law Association attracted an attendance so large that the meeting was held in Franklin Hall with an overflow audience in the Lecture Hall.

The Guy Marriner Lecture-Recitals were presented for their sixteenth season. These piano lecture-recitals on music by great composers continued to attract enthusiastic audiences.

A greater number of scientific, technical and educational organizations held regularly-scheduled meetings at the Institute. Internal activities, using our meeting rooms, also increased considerably. This extended use of the Institute's facilities for scientific and educational purposes is most gratifying.

LIBRARY

Acquisitions during the year totaled 5272. Of these, 762 volumes, 976 pamphlets, and 1092 maps were received as gifts from Institute members and friends of the Library, and from other societies and institutions through exchanges; 948 volumes were purchased from American and foreign publishers and comprise a fine collection of works in the fields of science and technology; and 1494 volumes were added through binding. The Library Committee secured some very fine rare items on Mechanics purchased through the James T. Morris Fund and some excellent works on Sugar through the Louis S. Ware Fund.

Patent specifications from the United States, Great Britain, and Switzerland were received regularly. All of the United States patents were bound by our staff, enabling us to have them continuously on file.

Through exchange and purchased subscriptions, the Library received regularly the most important periodicals and publications in science and technology. Several new publications were added to our collection.

The Library was used by 7696 persons. In addition to regular work, our staff furnished research information requested by mail and handled more than 5100 telephone calls. Over 11,000 photostats of Library material were furnished.

On January 1, 1953, the Library contained 143,000 volumes, 51,044 pamphlets, and 8068 maps, not including numerous unbound periodicals and uncatalogued books and pamphlets.

JOURNAL OF THE FRANKLIN INSTITUTE

The JOURNAL OF THE FRANKLIN INSTITUTE commemorated the 200th anniversary of Franklin's famous "Philadelphia Experiment" by devoting the May 1952 issue to the subject of lightning protection. The four papers by eminent authorities made this issue one of the finest we have published. The issue will also be remembered as the first one with an over-all cover picture.

In December the Publications Committee approved a plan to publish monographs under the auspices of the JOURNAL. Because of their length, these monographs will be separate pamphlets but will conform to the high standards maintained in our regular JOURNAL papers.

Seventy papers (an increase of thirty per cent over 1951) were submitted for consideration. Of these, twenty-two were published, and twenty-seven were added to the list awaiting publication. The greater number of papers submitted is an indication of the increasing recognition of our JOURNAL by the scientific world. In this connection, it is worthwhile noting that the number of paid subscriptions has increased ten per cent since 1949.

MUSEUM AND PLANETARIUM

Attendance exceeded that of any previous year with the exception of 1934 when the Museum was first opened. Comparative figures with 1951 are:

	Paid	*Free*	*Total*
1951	174,369	78,838	253,207
1952	205,302	79,848	285,150

Of these visitors, 126,291 came in organized groups. Attendance receipts showed an increase of $9237.

Exhibits:

The principal addition to the Museum was a new display in which the manufacture and application of steel are shown in surroundings attractively decorated by large photo-murals. Sponsored by Bethlehem Steel Corporation, it features self-operated exhibits demonstrating the properties of steel.

The Illusions Room was remodeled and now includes the distorted room—one of the most startling illusions known to psychologists—and other additional features.

A selection comprising 200 sheets of Nineteenth Century stamps from the Jefferys' Collection of United States postage stamps was displayed in specially-constructed cases.

The temporary exhibits and demonstrations to revive or to stimulate visitor interest were well diversified. The most noteworthy was the assembly of models, lent to us by International Business Machines Corporation, constructed from the scientific note-books of Leonardo da Vinci to celebrate the 500th anniversary of the birth of the Renaissance genius.

An amateur wireless station was placed in operation over week-ends, and Museum visitors enjoyed talking with other amateur stations in this and foreign countries.

"Energy in Action," a demonstration with numerous fascinating action exhibits, was presented by Westinghouse Electric Corporation and drew large audiences, as did General Electric Company's "Previews of Progress."

Fine furniture, plastics, machine tools, and other examples of handiwork by young craftsmen were displayed at the Annual Industrial Arts Exhibit sponsored by Ford Motor Company. This exhibition is designed to make known the work being done by the shop and drawing programs of local schools.

Interest in the annual Science Fair, co-sponsored by *The Philadelphia Inquirer*, increased among local students who were given this opportunity to display their skill in constructing objects of scientific interest.

Continued limited display space necessitated careful selection of new material for exhibit. Among the gifts and loans accepted were:

A jasper portrait medallion of Benjamin Franklin, from Hensleigh C. Wedgwood, New York.
Miniature models (16) of early automobiles, from A. J. Koveleski, Scranton, Pennsylvania.

Model rolling mill, from F. M. Beltrando, Coatesville, Pennsylvania.
Aluminum, from Mine to Metal, from Aluminum Company of America.
King Charles upholstered arm-chairs (2), from Mrs. H. B. Allen, Philadelphia, Pennsylvania.
Name-plate from Franklin's house in Paris, from Mrs. L. N. Conrad, Atlanta, Georgia.
Columbia Bicycle, from Westfield Manufacturing Company, Westfield, Massachusetts.
Endicott Limited locomotive cut-off model, from Franklin Railway Supply Company, New York.
Spanish Orrery, from Miss M. S. Hinchman, Gladwynne, Pennsylvania.

Special Activities:

Gross sales at the Book Counter exceeded those for 1951 by 50 per cent. A second counter was opened for week-end visitors.

The customary program of the Fels Planetarium on current events in astronomy was enlarged by two spectacular demonstrations: "The Creation of the Universe" (which had to be repeated to meet public demand) and "Flying Saucers." Over 5000 Cub Scouts attended Planetarium lectures on "The Winter Skies," which was especially adapted to their study theme for the month of January. In March, members of the Classical Society observed Latin Week by attending two special Planetarium lectures on "Classical Heroes in the Heavens."

Science Adventures for Young People attracted so many enthusiastic students that provision had to be made for an extra group. Winter Workshop continued to be popular among the young who like to find work for their hands. And the Pennsylvania Junior Academy of Science again held its regional meeting at the Institute, at which scientific papers were read and illustrated by the students.

COMMITTEE ON SCIENCE AND THE ARTS

The Committee on Science and the Arts met nine times, and thirty-three sub-Committee meetings were held. Twelve Medals and one Certificate of Merit were awarded at the annual Medal Day exercises. The Franklin Medal was awarded to Wolfgang Pauli. Henry B. Allen, Theobald F. Clark, Thomas D. Cope, George S. Crampton, Lionel F. Levy, and Morton M. Price each received a George A. Hoadley Certificate for thirty-five years of service on the Committee.

RESEARCH LABORATORIES

The Bartol Research Foundation (Swarthmore, Pennsylvania):

The Bartol Research Foundation continued to engage upon researches in nuclear physics and cosmic rays, in problems of the solid state with particular relation to thermionic work, and in the secondary emission of electrons from metals. Researches were also continued on the subject of light emission from phosphors, again in relation to phenomena of the solid state.

The small linear accelerator continued to function in researches on electron reflection from solids, and a new accelerator to produce higher electron energies is in process of construction.

The small Van de Graaff generator has been greatly improved in its efficiency of operation and has been engaged upon problems pertaining to the scattering of neutrons from matter. The large Van de Graff generator has been completed to its full height and will soon be functioning in a regular program of work.

Permission having been obtained from local authorities to utilize the garage on the Springfield property for laboratory purposes, the Cockcroft and Walton set (referred to in our last report) will be moved to that site and set up there as an independent unit.

Cosmic ray researches are being carried on in a series of flights in the Himalayan Mountains in India, and preparations for other work of an expeditionary nature are going on at the main laboratory in Swarthmore.

The laboratory continued to attract researchers from other countries. At the present time, two scientists from India are working here under the general sponsorship of their Government, and another application to take advantage of the facilities of the laboratory is under consideration.

The general training program, in which the Bartol Research Foundation and The Frank-

lin Institute Laboratories for Research and Development are participating, continued to function satisfactorily.

It should be noted that close cooperation between the two laboratories also has continued in technical projects. These projects have included Geiger counter technique, and certain bioengineering work such as guidance devices for the blind. And the Director of the Bartol Foundation, W. F. G. Swann has continued as a Senior Technical Adviser to the Laboratories for Research and Development, furnishing invaluable help on projects including the National Asphalt Research Center work, atomic energy for power development, friction, electret research, and problems in dynamics.

The shop and glassblowing facilities of the laboratory continued to render efficient service to the general needs of our researches.

The laboratory as a whole was operating under six Government contracts, and its potentialities were further enhanced by its own budget.

Biochemical Research Foundation (Newark, Delaware):

The Biochemical Research Foundation had a fruitful year. All departments were active, and coordination good. The full quota of experienced research scientists has not yet been achieved, but advance was made in that direction.

While many different phases have been followed, there are two main efforts which have a direct bearing on cancer research: One is of great importance as it opens an entirely new area in cancer research—a new point of view with a scientific basis in contradistinction to the former experiment-and-error type of research which may or may not strike the mark. It is based on the fact that all cells are in the main dependent upon the glycolytic metabolism (glucose adaptation) for their energy, growth and maintenance; and the cancer cell more than any other. Then all chemical processes in the body are dependent upon enzyme action which has two factors: the enzyme and the substrate upon which it works and adapts. This substrate is glucose. So our efforts have been to find a substance sufficiently like glucose to satisfy the enzyme so that it would not attack glucose, or, as we say, "inhibit the glycolytic metabolism." The Foundation has been particularly successful in this, but there are a number of "bugs" still to be worked out. However, it has the satisfaction of having had its premise confirmed by other good experimentalists. It is interesting to note that the Foundation began to work on enzymes in cancer in 1932, and this is now bearing fruit.

Another project is a revival of an idea conceived fifteen years ago: As ultraviolet light of the range of Å 2536 is the most lethal force known for cells, it might be applied to cancer cells. There are difficulties because of the very limited penetration of ultraviolet light. If it can be applied directly to the cell at that wave length, it will kill instantly. Although the first effort was not successful, more recent work by the physicists opened up new methods and avenues; and advantage is being taken of these to see if they can be applied to the treatment of cancer. In this study, there was very satisfactory cooperation between the Biochemical and Bartol Foundations.

A study of diabetes was completed for the doctors of the Wilmington Hospital, where trained people from the Foundation worked with the hospital's apparatus on their clinical problems.

The Foundation's Library continued to grow. The reprint collection now numbers 43,700—indexed, classified, and readily available. The cyclotron was overhauled and practically remade so that it works well. The microchemical laboratory gives usual service as well as does the Beams high-speed centrifuge and the electrophoresis apparatus.

The Franklin Institute Laboratories for Research and Development (Philadelphia, Pa.):

In every respect 1952 was the best year the Laboratories have had since their inauguration. The rate of growth experienced during 1951 was sustained, and accelerated in many respects. Briefly, the Laboratories executed research and development projects whose total volume was $2,600,000; over 72,000 square feet of space were in use at the close of the year; and 300 persons were employed.

The following statement, in approximate figures illustrates this growth:

	1950	*1951*	*1952*
Revenue from Industrial Projects	$ 234,000	$ 212,000	$ 252,000
Revenue from Government Projects	1,333,000	1,909,000	2,306,000
Total Revenue	$1,567,000	$2,121,000	$2,558,000
Square Feet of Space Occupied	57,000	57,000	72,000
Technical Personnel		211	250
Total Personnel	211	274	300

Projects:

Our program for industrial research is growing at a pace that is only suggested by the figures given above. Recognition by industries in the fast-developing Delaware Valley is widening and influencing many new industries to bring their problems and plans to us. Because of continued needs for national preparedness, the greater portion of our clientele is composed of Government agencies, both military and non-military; and the increase in volume can be attributed to the Government's continuing confidence in our work.

The year 1952 saw the beginning of thirty-five new projects for individual companies. In addition, four new cooperatively-sponsored projects were put under way; and blueprints for new cooperative projects were being drawn. These projects are similar to the two-year-old National Asphalt Research Center. Three are sponsored by trade associations which draw their members from many states throughout the country; the other is sponsored by several companies in the middle-Atlantic area. The sponsors are aware of the many advantages found in projects of this sort. Among them: Smaller industries are able to afford a thorough research program by joining other companies in the industry—and these projects are generally wide in scope and deal with investigations into non-competitive areas.

Three of the new cooperatively-sponsored projects can be mentioned. The Association of American Railroads (central coordinating and research agency of the American trunk-line railroad industry) is supporting a project to determine the effect of bearing materials on the overheating of journal bearings, particularly where lubricants might be in short supply. This program, coupled with other research projects currently underway in other laboratories, represents an effort of the Association to eradicate the hot-box nuisance. A second project is sponsored by seven electrical power companies in Pennsylvania, Delaware, and New Jersey, and calls for installation of an alternating-current network analyzer at the Institute. This $400,000 miniature power system will be used to aid the sponsors in studying their facilities for generating, transmitting, and distributing electric power. The third cooperative project, the American Iron and Steel Institue, called upon us to formulate design specifications for the use of cold-rolled Type 301 stainless steel in structures. After outlining a tentative design specification, the first year's program was largely concerned with checking certain existing stainless steel design data against theory.

The National Asphalt Research Center continues, with increasing support from industries, to turn the results of fundamental research on asphalts into useful channels.

Space and Equipment:

In an effort to relieve restrictions placed upon the Laboratories' work by limited space, the Institute rented space in the building at 21st and Race Streets, across the street from the old Court Building. Known as Annex No. 2, this building yields 14,500 square feet of space. By the end of the year, the new annex had been refurnished, and several offices and laboratories put into operation. Five older laboratories were completely re-equipped. Special mention should be made of an Ajax-Northrup High Frequency Induction Furnace, the gift of an anonymous donor.

New Fields:

In the Chemistry and Physics Division, a bio-engineering section was set up to handle a new line of endeavor that had its origin in our work on the projection magnifier. Scientists in

this section are exercising their knowledge and experience to develop and improve medical and biological apparatus. In the Mechanical Engineering Division, where increasing emphasis is being placed on the problems of friction and lubrication in industrial machines, plans were being made to set up a separate section to handle that work.

Publications:

Many technical papers written by staff members were published in scientific journals and trade papers. The Laboratories were well represented at important technical society meetings throughout the year, and numerous papers were contributed.

A sixteen-page brochure was issued to publicize the work of the Colloids Section of the Chemistry and Physics Division in the field of "Molded Products and Coatings." Response has been very satisfactory, and our prospects in this field are multiplying rapidly.

In September 1952, the first issue of a quarterly bulletin was published. Mailed to numerous Government agencies, industrialists, engineers, scientists, technical editors, and scientific writers, as well as to our sponsors, *Laboratory Report* draws attention to the diversified activities of our Laboratories.

MEMBERSHIP

It is pleasant to report that our total membership was 6626 on December 31st, a gain of 380 over 1951. A word of appreciation is due those members who proposed friends and acquaintances they thought would be interested in joining The Franklin Institute. Ninety per cent of the members on our roles at the end of 1951 were with us at the end of 1952.

Science Is Fun lecture-demonstrations continued to be a popular activity. The three presented in 1952 were: "Glass Comes of Age," by Harold G. Vogt, Research Physicist of the Corning Glass Works; "Magazine Magic," by E. Huber Ulrich and Louis H. Palmer of The Curtis Publishing Company; and "The Hub of the Universe," a new planetarium demonstration based on the research of Bart J. Bok of the Harvard College Observatory, who was the guest speaker.

At the dinner preceding Dr. Bok's lecture, gold keys—in recognition of fifty consecutive years of membership—were presented to John P. B. Sinkler and Kern Dodge, who was represented by his son, Donald.

Interest continued in our Meet the Staff programs. By limiting attendance to approximately fifty persons, members were given an opportunity to meet the staff personally and to talk with them informally about their work at the Institute. Nine such meetings were held, and the exhibits covered included the Illusion Room, Bell Telephone, Library, Ham Radio, Science Fair, Link Trainer, and the Observatory.

Early in the year, a long-time member of the Institute wrote "An institution to be successful and survive, must have a growing membership of young persons . . . . It seems to me the greatest hope of building a vigorous membership lies in interesting young persons." With this thought in mind, fifty students with scientific interests were selected to receive the first Student Memberships sponsored by this member. Each membership will be renewed for four successive years if use of Institute facilities indicates an active interest on the part of the recipient; and new students will be eligible each year if the experiment proves successful. The donor prefers to remain anonymous at the present time because "If the project is successful my recompense will be an inner joy and gratification."

PERSONNEL

Our staff increased by 43—from 487 employees on Januray 1st to 530 on December 31st. Indoctrination of new employees included tours of the Institute. *The Filter* (an employees' house organ), parties sponsored by the Sunshine Club, and a Christmas party given by the Institute also contributed to bringing about a closer relationship among the widespread departments of the Institute.

In July, our first group of employees (those who were 65 or over on April 1, 1951, when the Institute elected coverage of its employees) became fully covered under Social Security. Jacob Heim, Institute gardener since 1944, retired on August 1st. John Wright, Museum guard since 1934, retired on September 10th. Several staff members who are over 75 are continuing in their positions and are collecting monthly Social Security benefits.

There is recorded with deep regret the deaths of five employees: Samuel Fenimore, receiving clerk, employed since 1942; Howard Gamble, porter employed since 1942; Felix Knoneberg, Museum guard, employed since 1948; Joseph Leone, Museum guard, employed since 1951; and Beatrice Reeder, Museum cashier, employed since 1951.

PLANT OPERATIONS

Additional changes were required in our buildings to accommodate our expanding activities, as well as alterations in Annex No. 2 mentioned under the Laboratories' report. After nineteen years, most of our equipment is requiring constant maintenance and repair. Equipment in the main building gets more than normal usage as this building is open seven days a week and practically every evening, and our meeting rooms and exhibition spaces were even more extensively used during 1952 than in previous years.

PUBLIC RELATIONS

A weekly radio program—"The Voice of The Franklin Institute"—was inaugurated in July over Station WDAS (1400 kc.) and is presented by the station at no cost to the Institute as a public service. Broadcast every Sunday afternoon, the half-hour show features science news, interviews with staff members and exhibitors in the Museum, and brief stories of Franklin and of the Institute.

The Institute News, with an increased circulation, was published ten times during the year. Speeches and personal appearances of personnel before scientific, industrial and civic groups continued on a high level. In addition, hundreds of inquiries pertinent to Benjamin Franklin and The Franklin Institute were handled.

Promotion of special Museum exhibits, Planetarium demonstrations, and Institute meetings was expanded with gratifying results. Other special events—such as the Marriner Lecture-Recitals, Ford Industrial Arts Award Exhibit, and Science Fair—were promoted. Finally, Medal Day received special attention which resulted in giving due prestige and recognition to The Franklin Institute and this internationally-known annual tribute to men of science.

Needless to say, the continued cooperation of all media of public information—press, radio, and television—is warmly appreciated.

HOSTESS COMMITTEE

The Hostess Committee continued to earn our gratitude for its interest in the Institute. Continuation of the grounds-improvement program was the Committee's main project for 1952.

FRIENDS OF FRANKLIN

The group of 190 public-spirited individuals and 81 companies known as "Friends of Franklin" continued its generous support of the Institute, contributing $25,242.50 in 1952.

ENDOWMENTS

The moral and material help of "Friends of Franklin" has been of inestimable value to the Institute. However, we realized that while such current annual giving was essential to our work, a crying need existed for endowment—particularly unrestricted endowment. It was accordingly decided to organize an Endowment Department, which started officially on October 15th. Its main function will be to correlate and guide our activities in connection with raising permanent funds.

No formal fund-raising campaign is contemplated, but it is planned to have a continuing program to keep individuals and business organizations informed of our needs and of the desirability of helping to meet them. As earlier reports have pointed out, the Institute needs funds for the development and enlargement of its Museum educational activities, and even for supporting those it is already carrying on; for engaging in self-sponsored research work in its Laboratories; for the purchase of books for its Library and particularly for the binding and cataloguing of material to make the Library of more use to the public; and for all the general, routine, undramatic operations without which other activities could not exist. The more than 125 years of service which The Franklin Institute has rendered to the City, State, and Nation

merit support; and the present generation must carry forward the work so well initiated by the founders. It is hoped that our new Endowment Department is going to be of great service and help in coordinating our efforts.

FINANCES

The financial position of The Institute at December 31, 1952 as compared with December 31, 1951 is shown in the following summarized comparative statement adapted from the statement certified by our auditors (Messrs. Lybrand, Ross Bros. & Montgomery) which is available to members for examination in the office of the Treasurer:

Assets	*Dec. 31, 1952*	*Dec. 31, 1951*
Operating Funds		
Cash	$ 149,180	$ 146,021
Amounts due on laboratory research contracts	486,382	375,191
Other receivables	27,390	47,737
Inventories	44,297	38,967
Deferred charges	19,283	17,065
Total operating funds	$ 726,532	$ 624,981
Endowment Funds		
Investments at book values (market values $5,685,804 and $5,262,379, respectively)	$4,389,306	$4,120,854
Uninvested principal cash (overdraft in 1952)	(1,726)	22,017
Advances to operating funds	51,000	51,000
Advances to plant and property funds	45,000	145,000
Income cash	62,439	71,247
Total endowment funds	$4,546,019	$4,410,118
Plant and Property Funds		
Cash	90,784	784
Building, equipment, fixtures (less reserves for depreciation of $1,008,710 and $846,649, respectively	3,651,089	3,719,324
Advances to operating funds	338,903	366,218
Total plant and property funds	$4,080,776	$4,086,326
Total Assets	$9,353,327	$9,121,425

Liabilities and Funds	*Dec. 31, 1952*	*Dec. 31, 1951*
Operating Funds		
Accounts payable, accrued expenses, and deferred income	$ 298,227	$ 170,234
Advances from endowment funds	51,000	51,000
Advances from plant and property funds	338,903	366,218
Capital stock	10,430	10,480
Operating fund balance	27,972	27,049
Total operating funds	$ 726,532	$ 624,981
Endowment Funds		
General and restricted endowment funds and funds functioning as endowment including those of the Bartol Research Foundation	$4,483,579	$4,338,871
Undistributed and unexpended income	62,440	71,247
Total endowment funds	$4,546,019	$4,410,118

Plant and Property Funds		
Contributed funds	$3,945,776	$3,941,326
Advances from endowment funds	45,000	145,000
Advances for purchase of special equipment	90,000	—
Total plant and property funds	$4,080,776	$4,086,326
Total Liabilities and Funds	$9,353,327	$9,121,425

Comparative results of operations for the years 1952 and 1951 are given in the following summarized statement of income and expenses of the Operating Fund, also adapted from the auditors' report:

	1952	*1951*
Operating Revenue		
Membership dues	$ 60,722	$ 58,379
Museum admissions and other museum income	131,782	112,223
Laboratory research projects	2,557,637	2,120,905
Other activities	49,495	46,436
	$2,799,636	$2,337,943
Operating Costs and Expenses		
Museum	$ 322,397	$ 294,494
Library, net of amounts transferred to other departments	70,594	65,793
Laboratory research projects	2,412,804	2,012,074
Other activities	75,473	74,586
Administrative and general expenses, net of amounts transferred to other departments	78,013	77,101
	$2,959,281	$2,524,048
Operating loss	$ 159,645	$ 186,105
Other income		
Income from endowment funds	$ 87,413	$ 89,614
Gifts from Friends of Franklin	25,243	26,457
Appropriation, Commonwealth of Penna.	42,350	40,746
Other income	15,606	15,474
	$ 170,612	$ 172,291
Income before Other Charges	$ 10,967	$ (13,814)
Other Charges		
Interest	$ 4,589	$ 7,182
Cafeteria income	5,505	4,902
	$ 10,094	$ 12,084
Excess of income (excess of costs in 1951) transferred to Operating Fund Balance	$ 873	$ (25,898)

Respectfully submitted,

By order of the Board of Managers,

S. WYMAN ROLPH,
President

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS, JUNE 17, 1953

HONORARY

William Francis Gibbs

ACTIVE FAMILY

Albert J. Caplan
W. J. Davis
James J. Deeney
Harold Simmerman, O.D.
Richard A. Torgeson

ACTIVE

Paul A. Bein
Winthrop S. Casanave
M. B. Christy, Jr.
John L. Cronin
Peter Datcuk
Stanley Davies
Edward J. Fisher
Paul B. Goss, O.D.
Daniel K. Greenfield
E. J. Hesketh
Emil A. Hory
Charles J. Kriessman, Ph.D.
David H. Lawrence
Walter C. Mason
F. W. McCarthy
J. J. Mikita
Nikola P. Nikolich
George F. Power
Robert Robbins, M.D.
Robert Sahlin
Francis H. Scheetz
John F. Sheetz
Charles G. Simpson
George F. Vogt
John E. Wagenseller
E. L. Wildman
H. Frederick Wohlsen

ACTIVE NON-RESIDENT

Edgar C. Bain, Sc.D.
Bernard Cohen
Kenneth S. M. Davidson
John Strong, Ph.D.
L. B. Tuckerman, Ph.D.
Maxwell M. Upson
Hugh Van Valkenburgh
John B. Whitehead, Ph.D.

NECROLOGY

Eugene Y. Allen '40
Mrs. Elizabeth Bennett '48
James S. Halkett
Jesse G. Haydock '43
John J. McNally, O.D. '46
C. Frederick Rau '36
M. Amelia Robinson '36
Edwin J. Sharkey '52
Mrs. Isaac Tatnall Starr '36

JOURNAL OF THE FRANKLIN INSTITUTE

With the publication of Dr. Büchi's treatise on exhaust turbocharging of engines (see page 57 of this issue), the JOURNAL inaugurates a series of monographs which should prove to be valuable to scientists and engineers. The monographs meet the requirements of JOURNAL papers but, because of their length, cannot be included in the regular issues. They are, therefore, published separately and are available through the JOURNAL office at $1.00 each.

The following papers will appear in the JOURNAL within the next few months:

MINORSKY, N.: On Interaction of Nonlinear Oscillators.

MARIN, JOSEPH AND JOHN A. SAUER: Plastic Stress-Strain Relations under Radial and Non-Radial Combined Stress Loading.

KLINGER, H. H.: Microwave Physics.

SWANN, W. F. G.: The Case of Charged Density Distribution *versus* Semi-Permanent Polarization as a Basis for Electret Behavior.

COULSON, THOMAS: The Story of Domestic Lighting.

BERGER, W. J. AND EDWARD SAIBEL: On the Inversion of Continuant Matrices.

LEE, J. F.: The Thermodynamics of Critical Phenomena in Gases.

KU, Y. H.: A Method for Solving Third and Higher Order Nonlinear Differential Equations.

LANGHAAR, HENRY L.: The Principle of Complementary Energy in Nonlinear Elasticity Theory.

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, June 10, 1953.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JUNE 10, 1953.

COLONEL HIRAM B. ELY in the Chair.

The following reports were presented for final action:

No. 3266: Work of William Blum.

This report recommended the award of an Elliott Cresson Medal to William Blum, of Chevy Chase, Maryland, "In recognition of his long continued and unusually meritorious work in creating a modern scientific basis for the electrodeposition of metals, and for his development of useful processes in that field."

No. 3268: Levy Medal.

This report recommended the award of the Louis E. Levy Medal to George C. Newton, Jr., of Cambridge, Massachusetts, "In recognition of his outstanding paper, 'Compensation of Feedback-Control Systems Subject to Saturation,' appearing in the October and November, 1952, issues of the Journal of The Franklin Institute."

No. 3269: Ballantine Medal.

This report recommended the award of the Stuart Ballantine Medal to David G. C. Luck, of Princeton, New Jersey, "For his invention of the Omnidirectional Radio Range, an essential element in present day air traffic control."

No. 3270: Brown Medal.

This report recommended the award of the Frank P. Brown Medal to Frank Lloyd Wright, of Taliesin, Wisconsin, "In consideration of his very extensive contributions to the entire field of architecture over a period of more than half a century, by means of countless and varied buildings, by reason of his many writings and lectures and through his Fellowship at Taliesin."

JOHN FRAZER,
Secretary to Committee

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A. M. until 5 P. M. on Mondays, Tuesdays, Thursdays and Fridays; 2 P. M. until 10 P. M. on Wednesdays; and 9 A.M. until 12 noon on Saturdays.

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NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, EXECUTIVE DIRECTOR

"OIL SERVES AMERICA"

For several years Sun Oil Company's exhibit of oil production and refining has been one of the most attractive exhibits in the Museum, but this has been replaced by one of greater extent in which the display arts of motion, light, and color have been employed to present a fascinating story of how "Oil Serves America." The exhibit is a self-contained unit, enclosed on all sides, and with its own entrance and exit. Museum visitors will greatly appreciate the fact that it is air conditioned for their comfort.

Employing the most modern techniques of visual education, it comprises twelve separate units in which two- and three-dimensional highly colorful exhibits present the complete story of oil. A small theater where slides and motion pictures will be shown to supplement the other features has been included. Sun Oil Company personnel are in attendance to serve as lecture-demonstrators.

Visitors will, after entering, pass through a broad curving corridor which encompasses the whole exhibit where they will find the decorative units which tell a continuous, well-integrated story of the petroleum industry in its historical, technological, social, and economic aspects.

The story begins with a magnificent mural depicting civilized man's release from manual labor with the development of the petroleum industry, and his enjoyment of its contributions to the riches of today's living. Scale models contrast several obsolete methods of doing things with those in use today.

Moving on we come to a sweeping diorama of geological formations which shows how petroleum originates, where, and how it was formed from the remains of prehistoric marine animals is simplified by the display of fossils. A geophysical technique (the seismograph) widely used in mapping underground structures, is illustrated by an animated diagram.

Methods of drilling for oil, producing, and conserving it, are shown in a series of displays which will prove fascinating to the visitor, for the operating models, transparencies, etc., are supplemented by actual equipment which will make this aspect of the industry readily understood.

Natural gas receives lively treatment in all its aspects.

Succeeding units, each a work of art and ingenuity, display the progress of the oil from well to refinery and from refinery to consumer, with digressions to show the patient work of research and engineering which produces manifold useful products made wholly or partly from

petroleum and its chemical derivatives. The familiar features of the former exhibit will all be found, told in more attractive form in this new one, not omitting the catalytic cracking process, in which Sun was a pioneer.

The whole display goes beyond the technical features of the industry to show how petroleum serves America in the home, factory, and farm; in the air, at sea, and along the nation's highways. It will probably come as a great surprise to visitors to learn that 60 per cent of all synthetic chemicals used in the United States are derived from petroleum, but when the rich variety of the applications are seen, displayed in large plastic droplets (if any such huge drops can be called droplets), it will be recognized how deeply the petroleum derivatives have penetrated into our daily lives.

This exhibit is one of which the Museum has every reason to be proud, and every member should embrace the opportunity to see it.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

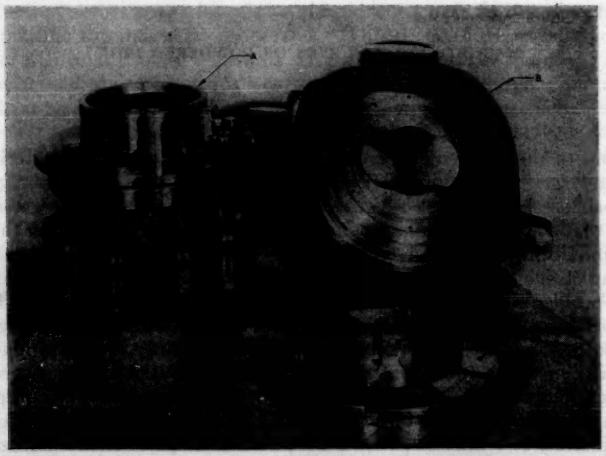
PIVOTED-SHOE BEARINGS*

BY

R. H. MARVIN

In performing a research project for the Navy Department, engineers in the Mechanical Engineering Division of the Laboratories evolved an unusual application for pivoted-shoe, oil-film bearings in hydraulic machines.

In positive-displacement hydraulic pumps and motors of the piston type, rolling contact bearings are often used to carry radial and thrust loads from rotating parts to stationary members. In hydraulic piston pumps, however, which usually start under low loads and run at essentially constant speed, it appeared that pivoted-shoe thrust and radial bearings might be used to better advantage because of their durability.



Components of the variable-displacement hydraulic machine, modified to employ pivoted-shoe thrust and radial bearings.

A—new socket ring
B—tilt plate
C—radial shoe
D—thrust shoe

* This work was carried out as a phase of investigation under Contract Nord 10625 with the Navy Department, Bureau of Ordnance.

To explore this possibility, Laboratories engineers modified a wobble-plate-type, hydraulic, variable-displacement machine. The rolling contact bearings which back up the socket ring were removed and, with only slight modification of the tilt plate, sets of radial and thrust shoes were substituted. The photograph shows the thrust and radial shoes and the new socket ring. The modified machine was subjected to a harmonic load cycle in which pressure in the lines was varied sinusoidally between zero and $\frac{2}{3}$ of the maximum allowable pressure. The period of this pressure cycle was two seconds. After continuous cycling for 381 hours, the pivoted-shoe bearings were found to be in excellent condition. Marks from the original scraping-in on the babbitted surfaces of the radial and thrust shoes were still quite clear at the termination of the test. Fluid used for the test was Navy power transmission fluid 51F21 (ORD) which has a viscosity of about 78 Saybolt Universal Seconds at 160°, the temperature maintained during the test.

The testing has shown that the pivoted-shoe oil-film bearings have a definite place in constant-speed machinery of this type.

No-load losses are higher with pivoted-shoe bearings, particularly if the speed is high. Whether the increased durability of the oil-film bearings more than compensate for their increased cost is still a question. Mass production methods applied to pivoted-shoe bearings might reduce their cost considerably.

MAGNETIZATION CURVES OF POWDERED IRON*

BY

A. D. FRANKLIN

One of the problems of greatest interest in the field of magnetism is the *a priori* calculation of the magnetization curves of ferromagnetic materials. In the past several decades a great deal of progress has been made in these calculations for bulk materials, using domain theory. A similar problem involves the same calculation for specimens consisting of fine powders dispersed in a non-magnetic supporting medium. This problem bears upon magnetic tapes and cores in particular. These Laboratories have begun a study of some of the features of the magnetization process in such specimens. A detailed study has been made of the way in which the intensity of magnetization approaches saturation in high fields for this type of material. Test specimens were prepared by mixing a fine carbonyl iron powder,[1] with an average diameter of approximately two microns, with a very fine silica powder in various proportions. A resin binder was added to these mixtures, and the specimens pressed in the form of small bars. Magnetic measurments were made with a Sanford-Bennett (1)[2] permeameter.

* This work was supported by the Office of Naval Research.

[1] This powder was supplied through the generosity of the General Aniline and Film Corporation.

The approach to saturation in all of these samples was found to follow approximately the normal law for "soft" magnetic materials. This law is expressed in the equation

$$I = I_s\left(1 - \frac{A}{H}\right)$$

in which I is the intensity of magnetization, H the field strength, and I_s the saturation magnetization. A is a parameter known as the coefficient of magnetic hardness. For those samples in which the volume fraction occupied by the iron powder was high, this approach to saturation was found to be accountable in terms of a theory proposed by Néel (2). The theory is based upon the presence of a small amount of nonmagnetic inclusions within the sample. For the very dilute samples, the experimental data and the theory were found to diverge, which must be expected since the theory was not designed for the dilute range.

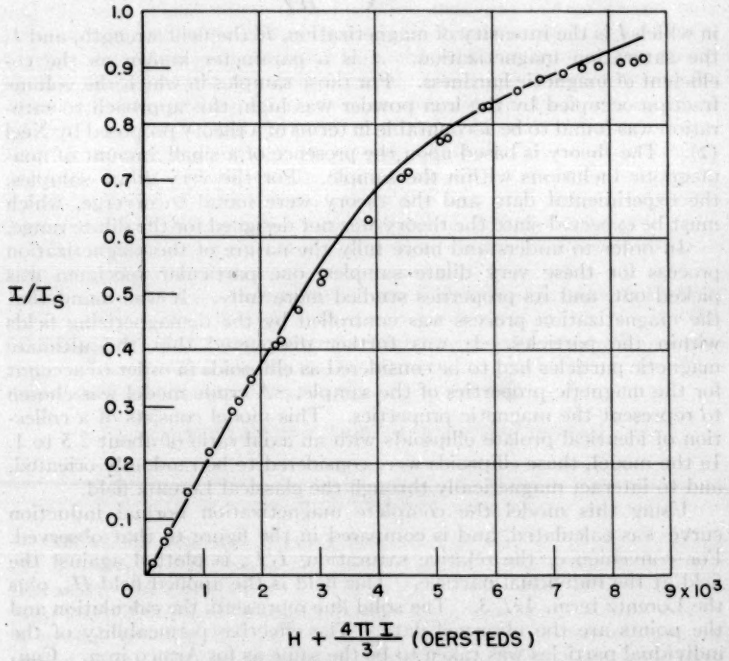
In order to understand more fully the nature of the magnetization process for these very dilute samples, one particular specimen was picked out, and its properties studied more fully. It was found that the magnetization process was controlled by the demagnetizing fields within the particles. It was further discovered that the ultimate magnetic particles had to be considered as ellipsoids in order to account for the magnetic properties of the sample. A crude model was chosen to represent the magnetic properties. This model consists of a collection of identical prolate ellipsoids with an axial ratio of about 2.5 to 1. In the model, these ellipsoids were considered to be randomly oriented, and to interact magnetically through the classical Lorentz field.

Using this model the complete magnetization normal induction curve was calculated, and is compared in the figure to that observed. For convenience, the relative saturation, I/I_s, is plotted against the field at the individual particle. This field is the applied field H_a, plus the Lorentz term, $4\pi I/3$. The solid line represents the calculation and the points are the observed data. The effective permeability of the individual particles was taken to be the same as for Armco iron. Considering the crudeness of the model, the fit is surprisingly good, and indicates that the magnetic properties are indeed controlled by the demagnetizing fields of particles or groups of particles behaving as ellipsoids. Further refinement could be made by considering a distribution of particle shapes and arrangements, but probably would not give much further information.

The carbonyl process for the preparaon of iron powders is nottied for the beautifully spherical particles it produces. A microscopic investigation of the sample itself was made in order to justify the use of ellipsoids in the model. Under the microscope it was found that the particles themselves often consisted of several spheres which had amalgamated in the process of growth, to form particles roughly ellipsoidal

[2] The boldface numbers in parentheses refer to the appended references.

in shape. Furthermore, in the pressed sample it was found that the particles often occurred in chains or in small groups whose over-all outlines were not spherical and which must have behaved magnetically somewhat like ellipsoids.



Magnetization curve P-818 No. 20.

From the magnetic standpoint, it appears necessary to consider the ultimate magnetic particles as ellipsoidal, and from the microscope examination this consideration seems to be justified. With such a model as this, it seems to be possible to calculate the shape of the magnetization curve of such a sample. Further work is now going on to see if the model can be extended to predict the effect of varying the dilution of the iron powder in the sample.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

IMPROVED ISOLATION OF L-ARABINOSE FROM MESQUITE GUM

BY

FRANCIS B. CRAMER

L-Arabinose is most easily obtained by the acid-catalyzed hydrolysis of mesquite gum. It has been shown by White (1) that controlled hydrolysis frees most of the arabinose leaving the rest of the polysaccharide molecule in the form of oligosaccharide fragments. The arabinose has ordinarily been separated from the by-products by one of two time-consuming methods. The first, the most recent refinement of which was contributed by the late C. S. Hudson (2), involves a tedious and hazardous fractional precipitation and extraction procedure. The second (3) necessitates prolonged mild hydrolysis, repeated dialyses and a final solvent fractionation.

A less cumbersome method has now been discovered for the removal of impurities with improved yields of L-arabinose. It is based on the fact that the major portion of the by-products contains uronic acid residues which are ionizable and may be easily removed by the use of ion-exchange resins. After hydrolysis in sulfuric acid, neutralization and filtration by established procedures (4), the solution is passed through columns of Amberlite IR-120 (5) and Duolite A-4 (6). The water is evaporated and the residual sirup dissolved in methanol. Arabinose separates in good yield as white, odorless crystals of purity sufficient for most uses without recrystallization.

EXPERIMENTAL

A 300-gm. quantity of crude mesquite gum (7) was tied in a square of cheese cloth and suspended in 1100 ml. of water in a 2-liter beaker. The gum dissolved on standing overnight. The cheese cloth bag containing bark, etc. was discarded. The solution was heated to 85° C. and acidified with 200 ml. of 27 per cent sulfuric acid (37 ml. of concentrated sulfuric acid diluted to 200 ml. with water). Hydrolysis was continued for 6 hours at 84°–86° C. after which the liquid was cooled and the acid neutralized with 70 gm. of calcium carbonate, capryl alcohol being used as foam breaker. The solution was left overnight at room temperature and filtered after the addition of 150 gm. of decolorizing charcoal. (The use of less charcoal may result in bothersome foaming during subsequent evaporation.) The filter cake was washed with 500 ml. of water which was kept separate from the main filtrate.

The solution and then the washings were passed slowly through a 110 × 5 cm. column of Amberlite IR-120 (**5**, **8**) and then through a similar column of Duolite A-4 (**6**, **8**). The columns of resin were washed with distilled water until a test of the washings with Fehling's solution showed negligible reducing power. The colorless effluent was concentrated in vacuum to a thin sirup. (If foaming occurs, it may be controlled by adding about 10 per cent of isopropyl alcohol to the solution before evaporation. The liquid is then passed slowly and continuously into the distilling flask through a separatory funnel.) A 50 ml. portion of methanol was then added and evaporated in vacuum to assist in dehydration. This was repeated until crystallization began, whereupon the material was rinsed into a beaker with 200 ml. of methanol. After crystallizing overnight at room temperature, the arabinose was filtered out and washed with 100 ml. of methanol. The yield was 114 gm. of material with an equilibrium specific rotation of +99.8° and a melting point of 147°–155° C. The mother liquor was concentrated in vacuum and the residue dissolved in 100 ml. of methanol. After one month at room temperature, this solution yielded an additional 27.5 gm. of crude material with a final rotation of +95°.

When the size of the batch was doubled, the capacity of the ion-exchange columns used was apparently exceeded. As a result, a less pure product was obtained. For example, 600 gm. of mesquite gum yielded 194 gm. of arabinose with a final rotation of +98.5° and a melting point of 145°–152° C. Resin columns of the size described could probably hold the ionizable impurities from as much as 450 gm. of mesquite gum without difficulty.

The method here described combines the older rapid hydrolysis procedure with a quick and easy method for removing by-product impurities. This results in a substantial saving in time and materials and removes the hazard involved in the use of large volumes of flammable organic solvents.

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(4) Circular of the Natl. Bur. Stand. C 440, "Polarimetry, Saccharimetry and the Sugars," F. J. Bates and Associates, Govt. Printing Office, Washington, D. C., 1942, p. 457.
(5) A product of Resinous Products and Chemical Co., Washington Square, Philadelphia 5, Pa.
(6) A product of Chemical Process Co., 901 Spring St., Redwood City, Calif.
(7) Obtained from Martin Drug Co., Tucson, Arizona.
(8) H. G. FLETCHER, JR., H. W. DIEHL AND C. S. HUDSON, *J. Am. Chem. Soc.*, **72**, 4546 (1950).

BOOK REVIEWS

LOGIC FOR MATHEMATICIANS, by J. Barkley Rosser. 530 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1953. Price, $10.00.

As its title suggests, this book, by one of the most distinguished logicians of our day, is a text which develops in great detail a particular system of symbolic logic with the interests and needs of mathematicians always providing the motivation. It is a condensed and modernized version of the three volume work of Whitehead and Russell, *Principia Mathematica*. The fundamental relationship of class membership is not dealt with by means of a strict type theory, as in *Principia Mathematica*, but by a modification of type theory due to W. V. Quine, "New Foundations for Mathematical Logic," *American Mathematical Monthly*, Vol. 44, pp. 70–80 (1937).

In the first chapter, the need for and the benefits of a formal logical system are convincingly and engagingly set forth. Chapters II and IV treat the basic sentential connectives, "not," "and," "or," "if-then," and "if and only if," which are fundamental for mathematics and the other sciences. Here the basic units are sentences, and their combinations into compound sentences is presented axiomatically and by truth tables. Quantification theory, which is roughly the logic of "for all" and "for some," is the subject of Chapter VI. This logic allows the internal structure of sentences to be analyzed into predicates, variables, (or constants), sentential connectives, and quantifiers.

Professor Rosser next turns to the treatment of equality, descriptions (which are technical devices for introducing into a formal system names for variously needed entities), and class membership, in Chapters XI, XII, and XIII. The axiom of choice and related topics are discussed in Chapter XIV. Seven other statements, some of which go by the name of "Zorn's Lemma," are given and are proven to be pairwise equivalent and equivalent to the axiom of choice. Thus this part of the book is particularly timely. Professor Rosser rests his case in Chapter XV. He indicates a course of study leading from his book straight into the heart of classical analysis, and he incidentally clears up an hiatus that occurs in a well known function theory text.

On the negative side the reviewer would like to caution the uninitiated reader against an inaccuracy in Chapter III, page 51, sixth paragraph. There are other ambiguities of the use *vs.* mention variety, for example, page 83, third paragraph. These may be due to the author's attempt to follow mathematical usage as closely as possible instead of current syntactical conventions.

Limitations of space prevent the reviewer from noting more than a few features which he found of special interest. A theorem about proof procedures is established which justifies the common practice in mathematical reasoning of dropping existential quantifiers and using some arbitrarily selected individual as the basis for further reasoning. The Russell paradox is very clearly explained, and several methods of avoiding it are indicated. There is an excellent discussion of function *vs.* function value, a distinction which is blurred by many mathematicians. This is particularly true of the authors of books on the differential and integral calculus. It is the reviewer's opinion that many of the difficulties encountered by college mathematics students could be traced to these fundamental confusions, and he heartily recommends Professor Rosser's analysis to students and teachers. Several principles of induction are presented, and the often neglected question of the justification of the procedure of definition by induction is given thorough consideration. The chapters on cardinals, ordinals, and the axiom of choice offer extremely valuable information for any one interested in foundational mathematics. Throughout Professor Rosser profusely illustrates the formal principles and theorems by examples from standard mathematical texts. A wealth of interesting exercises is given. The typography is excellent.

LEON C. ROBBINS, JR.

TEAMWORK IN RESEARCH, edited by George P. Bush and Lowell H. Hattery. 191 pages, 16 × 24 cm. Washington, D. C., The American University Press, 1953. Price, $4.00.

This volume was adapted from the Proceedings of the Third Institute on Administration of Scientific Research and Development presented at Washington, D. C., by The American University with the cooperation of the National Research Council and the American Association for the Advancement of Science.

A host of distinguished experts contributed to these proceedings but space does not permit mentioning them all by name in this review. Whether those of us who are convinced that research is the unique product of a talented individual's efforts like it or not, team research is here to stay. One man research projects are becoming less common and group or team projects are becoming typical of present research methods. This change in the mechanics of carrying out research programs presents certain problems which the contributors to this volume discuss competently and clearly. The largest problems appear to be interpersonal relations on the team and the proper selection of team leaders.

A chapter entitled "Human Factors in Research Teamwork," by D. B. Hertz of Columbia University, stresses the importance of interpersonal relations on a research team. It is pointed out that the rank of individual members of a research team must be based on real ability differences for best results. To do otherwise would be to risk a serious conflict situation on the team.

A chapter entitled "Supervising and Training for Teamwork," by A. M. Rothrock of N.A.C.A., is particularly striking for the clear manner in which the author comes to grips with certain problems. It is pointed out that the men on a research team know who the best men in the organization are, every bit as well as do their supervisors. From this fact it follows that promotions based on anything but merit which is readily recognized by the people involved, will cause a general disintegration of spirit in the organization. In fact, Rothrock claims that it is generally better not to establish a position than to fill it incompetently. Furthermore, he points out that the greatest source of worker dissatisfaction in research teams is lack of respect for the boss. Certain requirements are set for the group leader. He must be technically competent in order to make it possible for him to achieve respect. The group leader must have an inherent sense of fair play—no man without this trait should ever be a group leader. The leader must lean over backward in the granting of credit to the men in his group. Furthermore, the leader must have scientific integrity and the ability to come to clear decisions.

This reviewer believes that this book is like a breath of the cool fresh air of logic in the fetid swamp of gibberish, when compared with some of the current discussions of research teamwork. I cannot recommend this book too highly for those men for whom its discussions are pertinent.

EZRA KRENDEL

ELECTROMAGNETICS, by John D. Kraus. 604 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1953. Price, $9.00.

Reviewing a book on electromagnetics is like reviewing an old play whose theatrical interpretation depends simply upon the new cast. John D. Kraus in writing his new book, *Electromagnetics*, has been able to do little more than reinterpret a subject which is not new.

It is at once realized that this subject is essentially basic, dealing largely with the physics of electricity. Hence, it is not a subject about which our knowledge changes very rapidly. The basic experiments in electrostatics were performed by Coulomb in 1785; James Clerk Maxwell introduced the concept of displacement current and postulated his generalized circuit equations in 1873; about 1831 Michael Faraday in London and Joseph Henry in Albany independently established the laws of electromagnetic induction; F. E. Newmann derived the more general form of Faraday's Law in 1845.

These equations together with boundary, continuity, and other auxiliary relations are the fundamental tools used today in the analysis of electromagnetic devices. Furthermore, to render these relations useful for the solution of specific problems, a large amount of mathematical and conceptual development has been carried out. The formal presentation of this material has been the primary task of writers on electromagnetic theory, and the development

of such texts has been undertaken many times since the original discoveries cited above. These works are well known to all students of physics and electrical engineering.

What can a new author attempt to achieve in writing another text on electromagnetic theory beyond what has been created by the contemporaries, Stratton, Slater, Schelkunoff, Smythe, and others? He can of course take advantage of the rapid advances in new applications, using these as illustrative examples of principles and working these applications into practice problems. This sort of revision may add interest to what may otherwise be a somewhat dry subject, but it has little teaching value, since most electromagnetic principles are best explained in terms of very simple analogies. More appropriate for a new text in this field would be a shift in emphasis to embrace the technical fields of current importance. This approach was well illustrated when, at the wartime peak of interest in microwaves and radar, J. C. Slater undertook the writing of a small volume on electromagnetic theory, entitled *Microwave Transmission*. At this time similar opportunities exist for slanting any new text, and John Kraus' background in antenna work could have offered him the same opportunity for emphasis had he so chosen to narrow his field of coverage.

Contrary to the latter suggestion, *Electromagnetics* devotes the first six chapters to statics. Here the treatment is highly conventional as is the book as a whole. One is forced to conclude that this volume consists primarily of a collection of well developed teaching notes; and, if an instructor is in need of a text for class work, John Kraus' book may serve that purpose with a little less strain on the students than would the writings of the other contemporary authors cited.

C. W. HARGENS

PROGRESS IN NUCLEAR PHYSICS, Vol. 2, edited by O. R. Frisch. 295 pages, diagrams, 16 × 26 cm. New York, Academic Press, Inc.; London, Pergamon Press, Ltd.; 1952. Price, $9.25.

This second volume in the Progress of Nuclear Physics series follows the same general plan as does the first volume. There are eight carefully written, well organized review articles on subjects of current interest in nuclear physics. These serve an extremely valuable purpose in making information available to the non-specialist in a highly palatable form. The authors, mainly English, are recognized authorities in their fields. They have made extensive reference to the morass of papers on nuclear physics and have produced a uniformly excellent distillate. The foreword to Volume 1 states that these books are "intended to help both the nuclear physicist in finding information in fields adjacent to his own, and the other scientist in getting an introduction to some technique . . . ." This aim has been achieved.

The papers and their authors are: 1. The Electron Optical Properties of Magnetic Beta Ray Spectrometers, by N. F. Verster; 2. Nuclear Paramagnetic Resonance, by R. V. Pound; 3. Luminescent Materials for Scintillation Counters, by G. F. J. Garlick; 4. The Neutron-Proton Interaction, by G. L. Squires; 5. Fission, by W. J. Whitehouse; 6. The Low-Lying Excited States of Light Nuclei, by W. E. Burcham; 7. The Nuclear Shell Model, by B. H. Flowers; and 8. Ionisation by Fast Particles, by T. E. Cranshaw.

These articles are comprehensive in nature and generally start with basic principles. With the exception of the paper on neutron-proton interaction, they can be read with profit by persons familiar with elementary nuclear physics. The paper on the nuclear shell model deserves special commendation. B. H. Flowers has given an excellent critical evaluation of the current theories which attempt to explain the success of this model.

If one must find fault with this well edited collection, then the small size of the illustrations and their captions should be criticized.

LEONARD MULDAWER

AN INTRODUCTION TO STATISTICS, by Charles E. Clark. 266 pages, diagrams, 15 × 23 cm. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1953. Price, $4.25.

The exact sciences, such as physics and chemistry, can go a long way without using statistics. But, on the other hand, statistics is almost an essential tool in such fields as the social sciences. However, workers in the social sciences fields frequently have insufficient

mathematical training to be able to use the methods of modern statistics. This book will be a great help to social scientists with little mathematical training, because it provides a good working introduction to statistics without requiring much more mathematics than high-school algebra. The big advantage this book has over most books on statistics at this level is that it features statistical inference, which is just the material required in the applications.

The book begins with four chapters covering the essential background material from probability theory, and then the remainder of the book is devoted to topics in statistical inference. The problems which are discussed are: the reliability of sample means and sample probabilities, the problem of when the difference between sample means is significant, problems requiring the analysis of variance, inferences made from chi-square, and linear correlation.

A very important point which is frequently emphasized throughout the book is the idea that in order to make the best possible inference, all the available information of an experiment should be used.

This text is well suited to self study because of the inclusion in the text of many worked out problems. These are well chosen to illustrate the applications. In addition, there are many problems to be worked out by the student, and the solutions to all the odd-numbered of these problems are given in fairly great detail. HAROLD PLATZER

SIMPLIFIED DRAFTING PRACTICE, by W. L. Healy and A. H. Rau. 156 pages, diagrams, illustrations, 22 × 29 cm. New York, John Wiley & Sons, Inc., 1953. Price, $5.00.

In this book the authors express the belief that all drafting practice should be scrutinized for conformance with the principle that drafting is a means of transmitting information.

As part of the industrial process, drafting has contributed much to our wealth and well-being, but it has not kept pace with the improvement it helped to achieve. Through tradition, draftsmen have retained many practices based on artistic expression rather than on the efficient transmitting of ideas.

The material for the book was the basis for reforms brought about in one of our largest industries through streamlined drafting practice. The direct and valuable suggestions should find application in many situations and be helpful to many people, including: draftsmen, interested in self-improvement; drafting supervisors, who might use these ideas to improve work output in their departments; students of drafting, who could quickly apply without prejudice the ideas presented. To engineering students it would serve as a practical approach supplementing more formal instructions.

Application of the methods outlined should increase the work potential of scarce technical people and the improved communications resulting should reduce errors and promote efficiency.

J. C. HESELWOOD

ERRATUM: In our May issue, p. 466, the price of *The Chemistry of Synthetic Dyes*, Vol. II, by K. Venkataraman, was erroneously listed as $10.00. Academic Press, the publisher, informs us that it should be $15.00.

BOOK NOTES

ELEMENTS OF ELECTRICITY, by William H. Timbie assisted by Alexander Kusko. Fourth edition, 631 pages, diagrams, illustrations, 15 × 22 cm. New York, John Wiley & Sons, Inc., 1953. Price, $5.50.

The tremendous growth in the electrical industry since 1937 is reflected in this revised fourth edition of Timbie's standard elementary text. In addition to new, up-to-date illustrations, the text has been revised to include material on aluminum wire, transistors, radar, television, ceramic capacitors and dry and gaseous rectifiers. The problems also have been modernized and now include ones on the applications of electronics and control and on heavy current industries. This modernized version of an outstanding elementary text will be warmly welcomed by teachers and students.

PHYSICAL FORMULAE, by T. S. E. Thomas. 118 pages, 11 × 17 cm. Methuen's Monographs on Physical Subjects. London, Methuen & Co., Ltd.; New York, John Wiley & Sons, Inc.; 1953. Price, $2.00.

A very useful selection of physical formulas has been gathered into this small book, designed as a reference for physics and engineering students and workers. It covers the principal laws and formulas in the following subjects: mathematics and statistics; mechanics, hydraulics, elasticity; general physics; acoustics and Fourier series; heat; light; electricity and magnetism; and electronic physics. Well-arranged and easy to use, the book should be a valuable aid for quick reference.

STARCH, by Charles Andrew Brautlecht. 408 pages, illustrations, 16 × 24 cm. New York, Reinhold Publishing Corp., 1953. Price, $10.00.

Designed to collect in one volume the basic information on starch and its uses, this new book offers up-to-date information on the sources of starch, its production and uses. Because the starch industry is so extensive, the book does not purport to include all the pertinent material; nor does it claim to be a manufacturer's guide. It is, rather, a contribution to general knowledge in the starch field, and should prove of interest to those concerned with the manufacture, chemistry and industrial uses of starch.

AMERICAN ELECTRICIANS' HANDBOOK, by Terrell Croft. Seventh edition, revised by Clifford C. Carr. 1773 pages, diagrams, 13 × 19 cm. New York, McGraw-Hill Book Co., Inc., 1953. Price, $10.00.

The seventh edition of this reference book for practical electrical workers has been revised to conform to the 1951 National Electrical Code. Aimed at the electrical engineer and the serviceman alike, the book includes the fundamentals of electricity as well as practical suggestions for repairing electrical equipment. In addition, it covers such specialized subjects as electron tubes, control generators, synchros, copper-oxide rectifiers, Signalite fuses, fluorescent lamps and farm wiring.

THE CHARACTERIZATION OF ORGANIC COMPOUNDS, by Samuel M. McElvain. Second edition, 303 pages, 15 × 22 cm. New York, The Macmillan Company, 1953. Price, $4.50.

Retaining the main features of the first edition (1945), this present work offers a completely revised chapter on the selection and preparation of derivatives. New problems are included in the chapters on the solubilities of organic compounds and on the experiments with the class reactions. The new material includes a section on amino acids and additional procedures for the preparation of derivatives.

The JOURNAL editors wish to call attention to the following new titles in the series of reprinted scientific books published by Dover Publications.

ORIGIN OF LIFE, by A. I. Oparin. Second edition, 270 pages, 14 × 20 cm. New York, Dover Publications, Inc., 1953. Price: $1.70 (paper); $3.00 (cloth).

WAVE PROPAGATION IN PERIODIC STRUCTURES, by Leon Brillouin. Second edition, 255 pages, diagrams, 14 × 20 cm. New York, Dover Publications, Inc., 1953. Price: $1.75 (paper); $3.50 (cloth).

COLLECTED WORKS OF BERNHARD RIEMANN, edited by Heinrich Weber. Second edition and the supplement, 558 plus 116 pages, 14 × 20 cm. New York, Dover Publications, Inc., 1953. Price: $2.55 (paper); $4.95 (cloth).

MATHEMATICAL RECREATIONS, by Maurice Kraitchik. Second edition, 330 pages, diagrams, 14 × 20 cm. New York, Dover Publications, Inc., 1953. Price: $1.60 (paper); $3.00 (cloth).

CURRENT TOPICS

Transistors for Television?—Tubeless radio and television receivers came a step closer to the American living room with an announcement by the General Electric Research Laboratory of a new means of producing germanium for transistors. Transistors, which require tiny bars of the element germanium, are the new devices capable of performing many of the electronic chores now done by more complicated vacuum tubes like those in radio and television sets.

Dr. Robert N. Hall, a young physicist in the laboratory, has developed a means for producing as many as 100 wafer-thin layers of specially treated germanium in a 6-in. ingot. Other methods produce only one or two of these vital layers. Dr. Hall emphasizes, however, that the new method is still in the laboratory stage.

Each of these layers contains germanium mixed with a trace of gallium. They are separated by thicker regions of germanium containing minute amounts of antimony.

One section of the "gallium-doped" layer in each transistor does the work of the grid in a vacuum tube, Dr. Hall explained. The "antimony-doped" layers take the place of the cathode and plate in a tube.

Using the new method, several thousand transistors can be produced from each ingot. The method will improve transistor performance and is expected to cut production costs. As a result, the new technique may permit the use of transistors for the first time in television sets.

Among disadvantages in the use of these tiny devices are their high cost and poor performance at high frequencies and at high temperatures.

Transistors are expected to make possible the construction of equipment ranging from tinier hearing aids to small-size "electric brain" machines that now take up an entire room.

Transistors as small as grains of rice also are expected to replace many vacuum tubes in telephone, telegraph and other communications equipment.

Other salient facts pointed out by Dr. Hall:

Transistors are expected to have a life expectancy at least 10 times that of tubes.

Transistors can operate on about one-millionth of a watt, but tubes require much higher power, about one watt, simply to heat the filament to the proper temperature.

Tubes are complicated devices of glass and wire, while transistors require only a chip of germanium about 40-thousandths of an inch square, insulating material and three wires.

Transistors can withstand shocks many times greater than those that shatter vacuum tubes.

New Surgical Sponge, "Ray-X."—A new type of surgical sponge, detectable by X-ray, has been announced by Parke, Davis & Company.

The Ray-X sponges, which are now available, incorporate a barium sulfate insert that is permanently fused to the gauze and detectable under X-ray.

"Occasionally, it is necessary for an exploratory re-operation to determine whether or not a sponge is present," the company said. "Now it is possible to make positive diagnosis of such a situation, without re-operation, by use of Ray-X sponges."

Parke-Davis pointed out that the X-ray detectable insert is dark in color to distinguish Ray-X from ordinary sponges. The barium sulfate insert does not deteriorate and is detectable for a long period of time.

Produced at Parke-Davis' Bay Division, Bridgeport, Conn., the sponges "are soft, non-toxic, pliable and non-abrasive with all cut edges folded in," the pharmaceutical firm said. Ray-X sponges can be sterilized in the usual manner, and no special X-ray techniques are required when using the sponges.

Production of Zirconium.—National Research Corporation of Cambridge, Mass., has disclosed a method for the production of zirconium which was developed under a research project sponsored by the Atomic Energy Commission. James H. Moore, Director of the Metallurgical Department of National Research Corporation presented a paper entitled, "The Preparation of Zirconium Metal by Arc Dissociation of Halides" at the Electronics Division spring meeting of the Electrochemical Society. The information presented was only recently released from security restrictions by the Atomic Energy Commission.

Since this is one of the few continuous methods for zirconium reduction which has been publicly announced in recent years, it has aroused considerable interest. Officials of National Research Corporation have pointed out that while the process described may be commercially interesting for production of special grades of titanium and zirconium, it should not be considered a satisfactory answer to the major problem of finding a cheap method for tonnage production of these metals. National Research Corporation, in partnership with Monsanto Chemical Company, is engaged in an intensive study of this latter problem.

Effects of Stereo Movies on Vision.—Three-dimensional motion pictures offer the American public an opportunity to uncover certain existing visual problems and to help train its eyes to overcome them, Hollywood's top cameramen, directors, and film technicians have been told.

Speaking in the Academy Award theater, Hollywood, before a meeting of the Society of Motion Picture and Television Engineers, R. A. Sherman, vision specialist of the Bausch & Lomb Optical Co. of Rochester, N. Y., said that some 12 to 15 per cent of the public now have eye problems which stereo movies will uncover.

The problems, he said, are those related to binocular (two-eyed) coordination in seeing. They include various heterophorias (conditions in which the two eyes are not properly aligned vertically or horizontally), aniseikonia (difference in the size or shape of the images in the retinas of the two eyes), anisometropia (unequal focus in the two eyes), and accommodative convergence disturbances (the eyes lack teamwork in turning and focusing). The eye difficulties which stereo movies can help overcome are the heterophorias

and the accommodative convergence disturbances, Sherman said. All of the eye conditions noted should have professional attention, he emphasized.

"The beneficial and powerful stimulus from properly produced and properly projected stereoscopic movies will put the identifying finger on some of us who, for our own general well-being, need visual attention and have not previously suspected it. Our eyes will accuse us of neglecting them," Sherman declared.

"One of the first indications to some of us who do need such attention and don't suspect it may be a feeling of tension or discomfort from viewing stereoscopic motion pictures."

According to statistics from the Bausch & Lomb occupational vision program analyzed by Purdue University researchers, Sherman said, one person in every five can profit from attention to his vision.

Improved Laboratory Standard D-C. Voltmeter.—An improvement in laboratory standard d-c. voltmeters has just been announced by Computer Corporation of America. The new unit, designated Model PVM-4, features a resolution of better than 50 millivolts over the entire range of 0 to 600 volts. The 0–10 volt scale affords resolution of better than 5 millivolts in that range. Accuracy is better than 0.2 per cent. Linearity is better than 0.1 per cent. Input impedance is infinite.

The PVM-4 is extremely rugged, completely protected against overload, and simple enough in operation to be equally suited to laboratory or production line use.

Essentially the PVM-4 consists of a super-regulated power supply, an accurately calibrated attenuator and a sensitive null indicator. The reference voltage for the power supply is furnished by a mercury battery with better than 1 per cent per year stability. An internal Weston standard cell is provided for periodically calibrating the power supply to within 0.1 per cent of absolute value. The attenuator consists of a ten-turn potentiometer of 0.05 per cent linearity and fixed resistors matched within 0.025 per cent. The null indicator is a ruggedized zero-center meter with a sensitivity of 1 microvolt per division.

In use, the voltage to be measured is applied directly across one side of the null indicator. The attenuator is then adjusted so that its output, applied to the other side of the indicator, produces a null. At this point the two voltages are exactly equal and the value of the unknown may be read directly from the attenuator setting.

It is expected by the manufacturer that the Model PVM-4 will find wide application, particularly in the testing of power supply regulation, analog computer measurements, meter calibration, capacitor storage measurements and battery voltage measurements.

Paper Snow Fence.—A snow fence made of two-ply paper with an inner layer of fiber and asphalt has been used experimentally in Michigan with generally satisfactory results. The sandwich filler of asphalt promotes resistance to moisture and gives strength and toughness. In tests, paper snow fencing withstood bad sleeting, heavy rain and high winds.

Detergents Used in Oil Fields.—Detergents, of composition similar to those used in the dishpan and washtub, can be used in the nation's oil fields to produce more oil, research scientists say. Tests in the Bradford field of Pennsylvania indicate that the value of additional oil produced was twice the cost of the detergents or "wetting agents." By this method, the chemicals were added directly to water injected into the earth under pressure to drive oil to existing producing wells.

0.25-Watt Axial Lead Resistor.—A new axial lead precision wirewound resistor for subminiature electric and electronic equipment has been developed by the Shallcross Manufacturing Company, Collingdale, Pa. The Type 18 resistor is rated at 0.25 watts, yet it measures only $\frac{3}{4}$ in. long by $\frac{9}{32}$ in. in diameter. Featuring a non-inductive winding and a standard tolerance of 1 per cent, the tiny resistor is available in resistance values up to 400,000 ohms.

The resistor's tinned axial wire leads are firmly anchored to the steatite bobbin. When processed with Shallcross BX impregnation, the Type 18 resistor will give reliable operation under prolonged exposure to high humidity. For less severe atmospheres, the resistor is available with lacquer coating.

Improved Radio Teletype.—An improved radio teletypewriter system which performs with considerably greater accuracy than the presently used systems was described by David B. Jordan, Earle E. Eldredge, and Walter Serniuk of Sylvania Electric Products Inc. to the engineers assembled for the National Conference on Airborne Electronics, in Dayton. The improved system was devised by the application of the principles of information theory which have been developed in the last decade according to Jordan who discussed the theoretical aspects of the system. He said that the advantages result from the use of six different frequencies within the bandwidth of the radio channel, rather than two as are presently used.

The accuracy of teletypewriter systems, especially under conditions of high noise, the authors said, is dependent upon the time duration of the electrical pulses which operate the receiver unit. The longer the pulse in time, the more accurate the printed results. With six frequencies rather than two, a simpler code is used and the duration of the electrical pulses is tripled. An advantageous reduction in effective operating speeds of the circuits is obtained while maintaining the same speed in terms of words per minute, plus a much higher degree of accuracy.

Eldredge and Serniuk described the laboratory equipment built to test out the theory and said that standard units are used throughout plus a new coding unit on the transmitting end, and a decoding unit on the receiving end. These units are used to translate the standard code of the presently used teletypewriters into the code adapted to the improved system, and back again. In this way standard equipment can be used to obtain the advantages of the improved system. They concluded that the laboratory tests confirmed the theoretical conclusions very closely.

Methods for Cooling Transistors.—Methods for cooling transistors so that they can be operated at relatively high power levels have been revealed by Dr. L. D. Armstrong and Dr. D. A. Jenny, of the David Sarnoff Research Center of the Radio Corporation of America.

The two RCA scientists, speaking at the annual convention of the Institute of Radio Engineers, pointed out that the electronic performance of the tiny germanium crystal in a transistor deteriorates when its temperature approaches 200° F. In the many low-power applications available for transistors, they explained, the power to be handled is too small to raise the temperature of transistors to the danger level. But in many other applications—higher power equipment such as audio amplifiers or apparatus that must be used in a confined space where ventilation is poor—transistors may become overheated and erratic.

To study ways of overcoming this temperature problem, Drs. Armstrong and Jenny designed transistors with built-in cooling systems. These experimental power transistors, which are about the size of a thimble, have already been made to handle one watt of electrical power as compared to about 5/100 of a watt maximum for uncooled transistors. (In further laboratory tests, using an external cooling means, such as air or water circulated around the transistor, the power types were operated at 3 watts.)

The two scientists discussed two approaches to built-in transistor cooling that have shown promise in the laboratory: liquid cooling and metallic cooling.

By the first method, a junction transistor (without the plastic case that normally surrounds its germanium wafer) is encased in a tiny metal tank which has been filled with a cooling liquid. The liquid transfers the heat generated in the transistor to the metal shell, from which it passes into the surrounding air. The liquid must be a good electrical insulator, have a high boiling point, and be thin enough for rapid circulation within the tank.

In metallic cooling, the transistor is encased in a metal cup which offers a relatively wide area for dissipating heat, or special cooling fins are attached to the outer casing. The metal cooling surface is connected by soldering it to the transistor's tiny wafer so that when the electrical power heats the germanium, excess heat is carried off to the outside cooling surface.

New Fiber Drum.—A new fiber drum for moisture proof shipments, tested by the Department of Agriculture, has been adopted by the Navy for domestic shipment of desiccants by Navy contractors. Steel, formerly, was required for this purpose. The drum contains a special aluminum foil barrier buried in the bottom and sidewall. The top is of metal. Tests proved no significant differences in steel and fiber drums exposed to high humidity conditions. The fiber drum performed satisfactorily in rough handling tests. Annual savings in shipping costs with the new drum are estimated at about $30,000 annually per company.

Cushioning Material Developed.—The serviceability of bonded shredded cellular rubber cushioning has been revealed by recent tests at the N. Y. Naval Shipyard with the development of a new material primarily derived from latex foam and scrap. The material is the result of a process of grinding selected odd and normal scrap materials from straight latex foam manufacturers. Coated with rubber binding, cured in molds to the desired shape and density, the material has the same resiliency and odorless properties of straight latex foam. It resists vermin and mildew and withstands wet cleaning. The material is expected to save one-third usual cushioning costs.